US011880506B2

(12) United States Patent
Rosenberg et al.

(10) Patent No.: US 11,880,506 B2
(45) Date of Patent: Jan. 23, 2024

(54) **HAPTIC KEYBOARD SYSTEM**

(71) Applicant: **Sensel, Inc.**, Sunnyvale, CA (US)

(72) Inventors: **Ilya Daniel Rosenberg**, Sunnyvale, CA (US); **John Aaron Zarraga**, Sunnyvale, CA (US)

(73) Assignee: **Sensel, Inc.**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **17/626,669**

(22) PCT Filed: **Oct. 5, 2021**

(86) PCT No.: **PCT/US2021/053660**
§ 371 (c)(1),
(2) Date: **Jan. 12, 2022**

(87) PCT Pub. No.: **WO2022/076480**
PCT Pub. Date: **Apr. 14, 2022**

(65) **Prior Publication Data**

US 2023/0229242 A1 Jul. 20, 2023

Related U.S. Application Data

(60) Provisional application No. 63/088,359, filed on Oct. 6, 2020.

(51) **Int. Cl.**
G06F 3/01 (2006.01)
H01H 3/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06F 3/016*** (2013.01); ***G06F 3/0202*** (2013.01); ***H01H 13/85*** (2013.01); *H01H 13/785* (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

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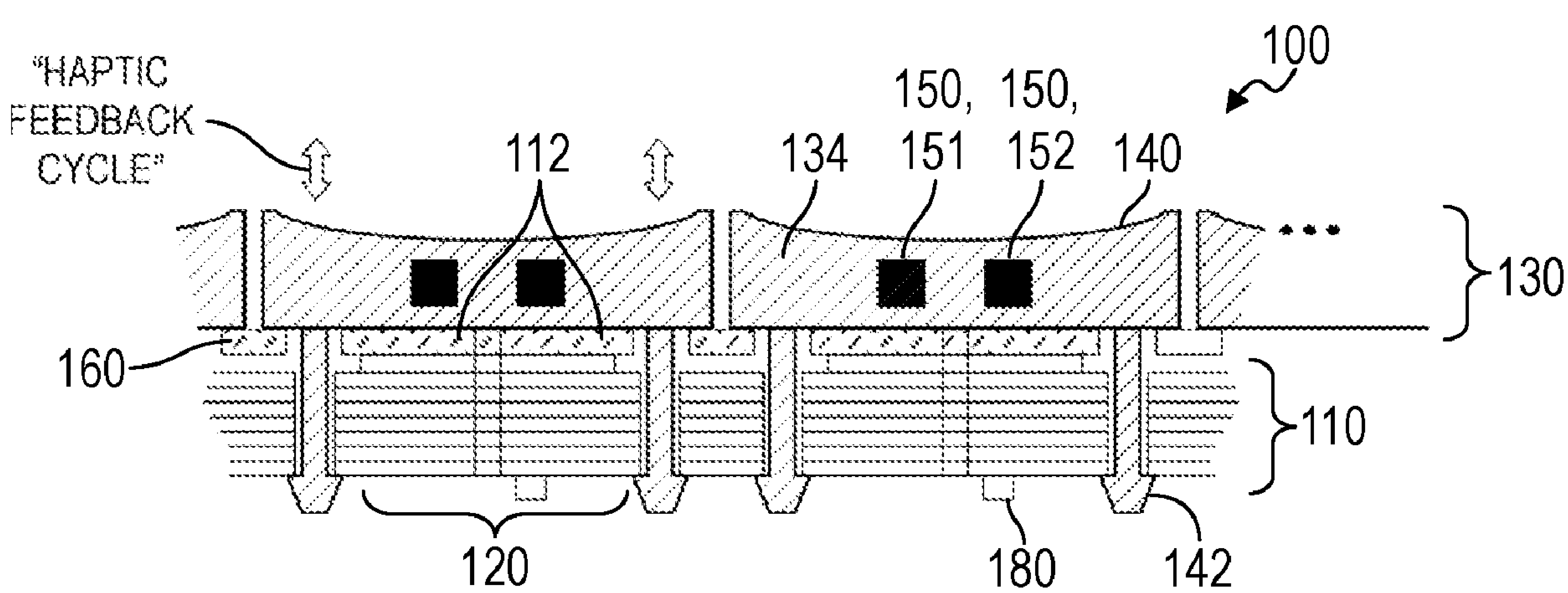
Primary Examiner — Krishna P Neupane
(74) *Attorney, Agent, or Firm* — Run8 Patent Group, LLC; Peter Miller; Alexander Rodriguez

(57) **ABSTRACT**

One variation of a keyboard system includes: a substrate including an array of inductors; a tactile layer arranged over the substrate defining an array of key locations over the array of inductors; an array of magnetic elements, each arranged within the tactile layer at a key location configured to inductively couple to an adjacent inductor and configured to move relative to the adjacent inductor responsive to application of a force on the tactile layer at the key location; and a controller configured to read electrical values from the inductors. In response to detecting a change in electrical value at a first inductor, the controller also configured to: register a first keystroke of a first key type associated with a first key location defined over the first inductor; and drive an oscillating voltage across the first inductor to oscillate the tactile layer over the substrate during a haptic feedback cycle.

20 Claims, 6 Drawing Sheets



(51) **Int. Cl.**
H01H 13/85 (2006.01)
G06F 3/02 (2006.01)
H01H 13/785 (2006.01)

(52) **U.S. Cl.**
CPC . *H01H 2003/008* (2013.01); *H01H 2201/036* (2013.01); *H01H 2215/05* (2013.01)

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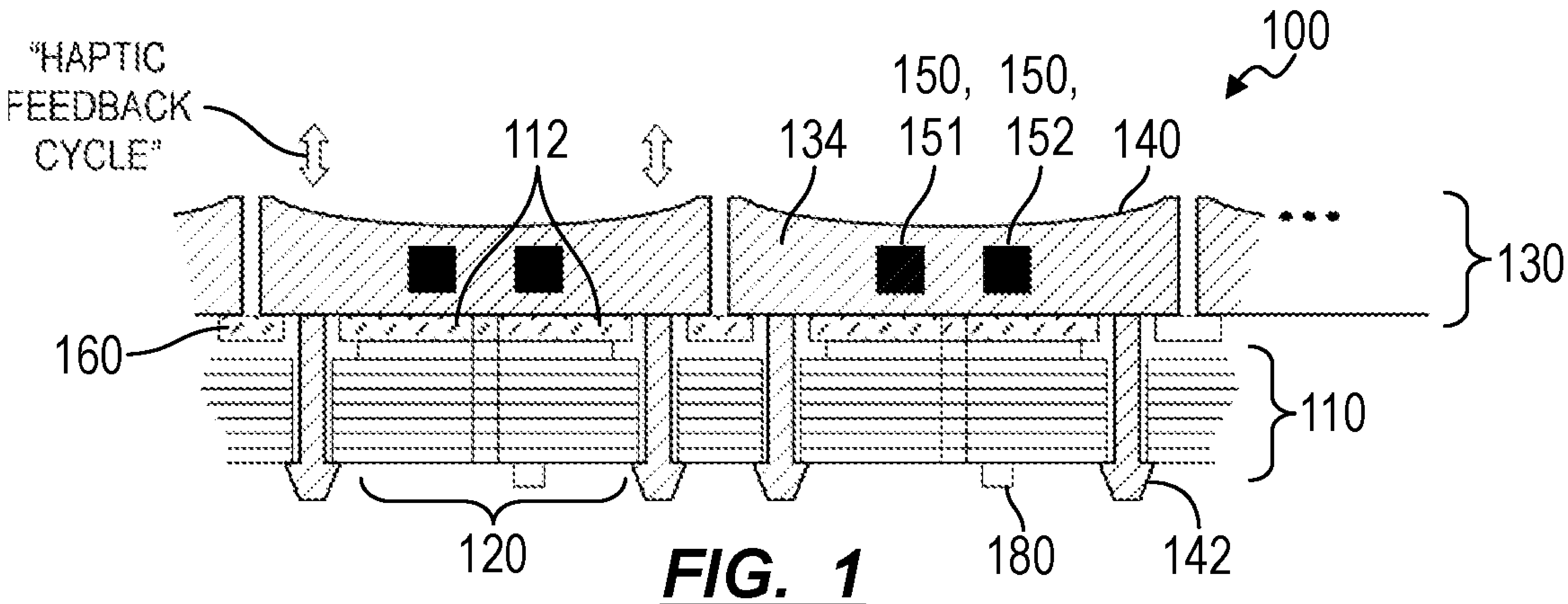

"HAPTIC
FEEDBACK
CYCLE"
100
150,
151
150,
152
112
134
140
130
160
110
120
180
142

FIG. 1

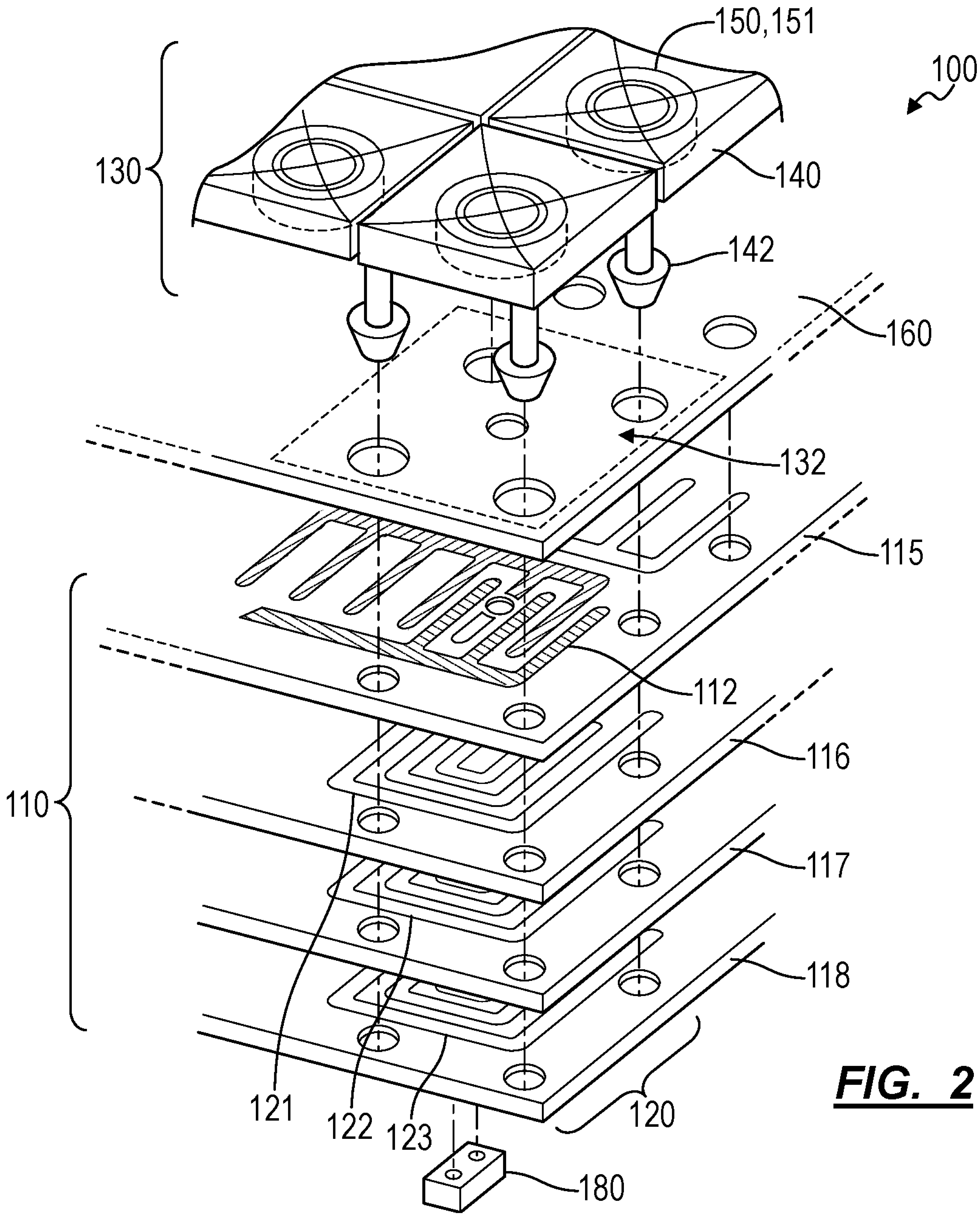
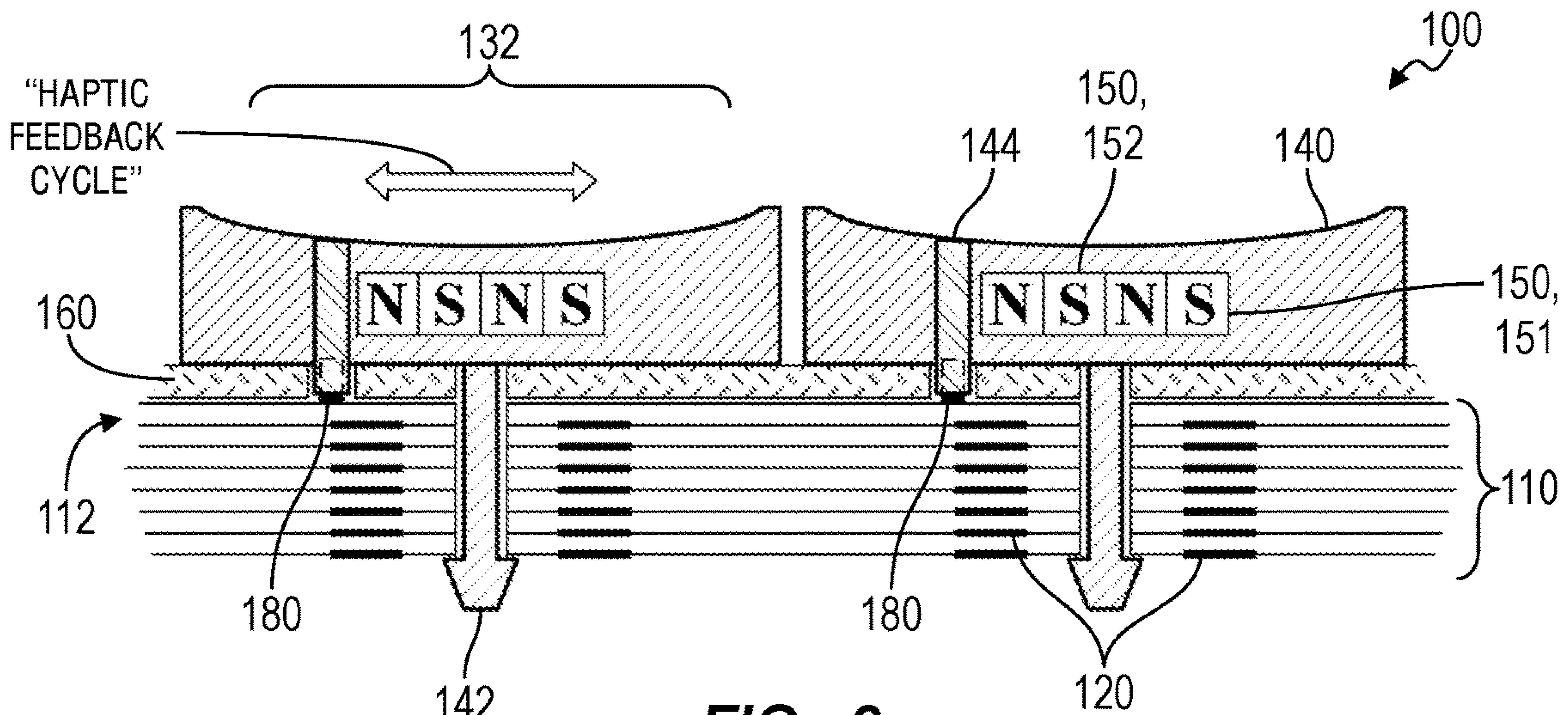
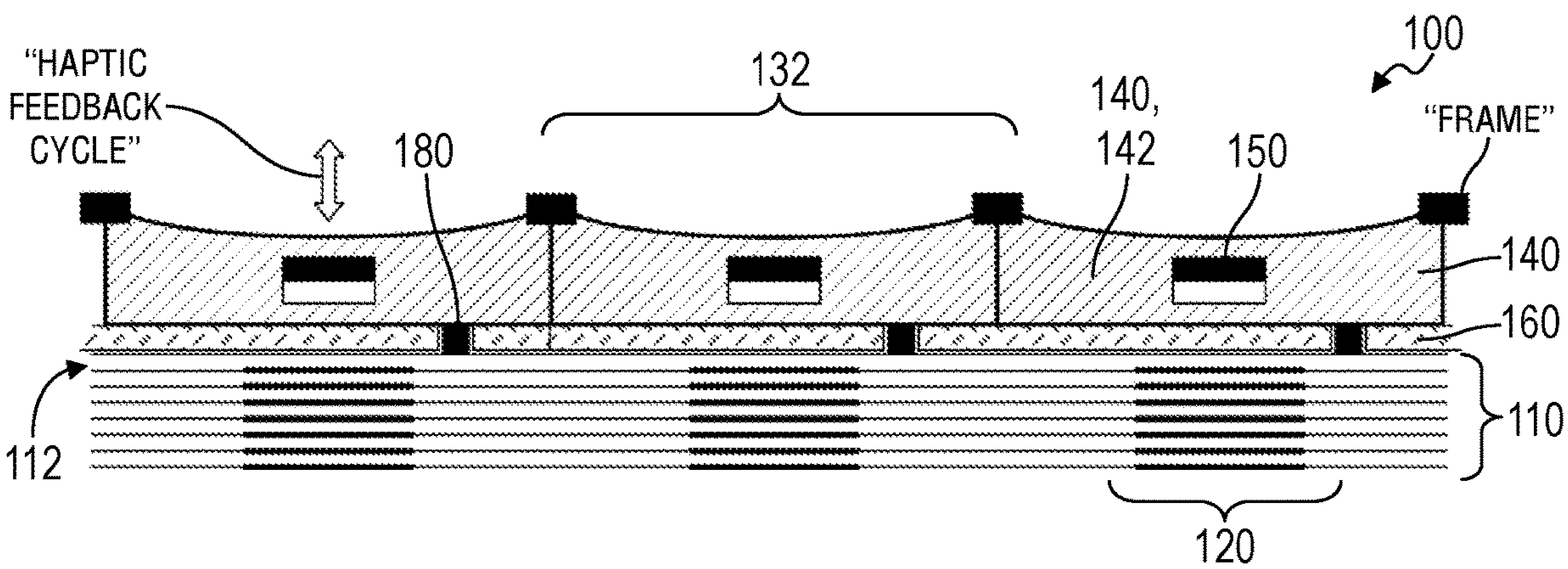

150,151
100
130
140
142
160
132
115
112
110
116
117
118
121
122
123
120
180

FIG. 2



100
132
"HAPTIC FEEDBACK CYCLE"
150, 152
144
140
N S N S
N S N S
150, 151
160
112
110
180
180
142
120

FIG. 3



100
"HAPTIC FEEDBACK CYCLE"
132
140, 142
180
150
"FRAME"
140
160
110
112
120

FIG. 4

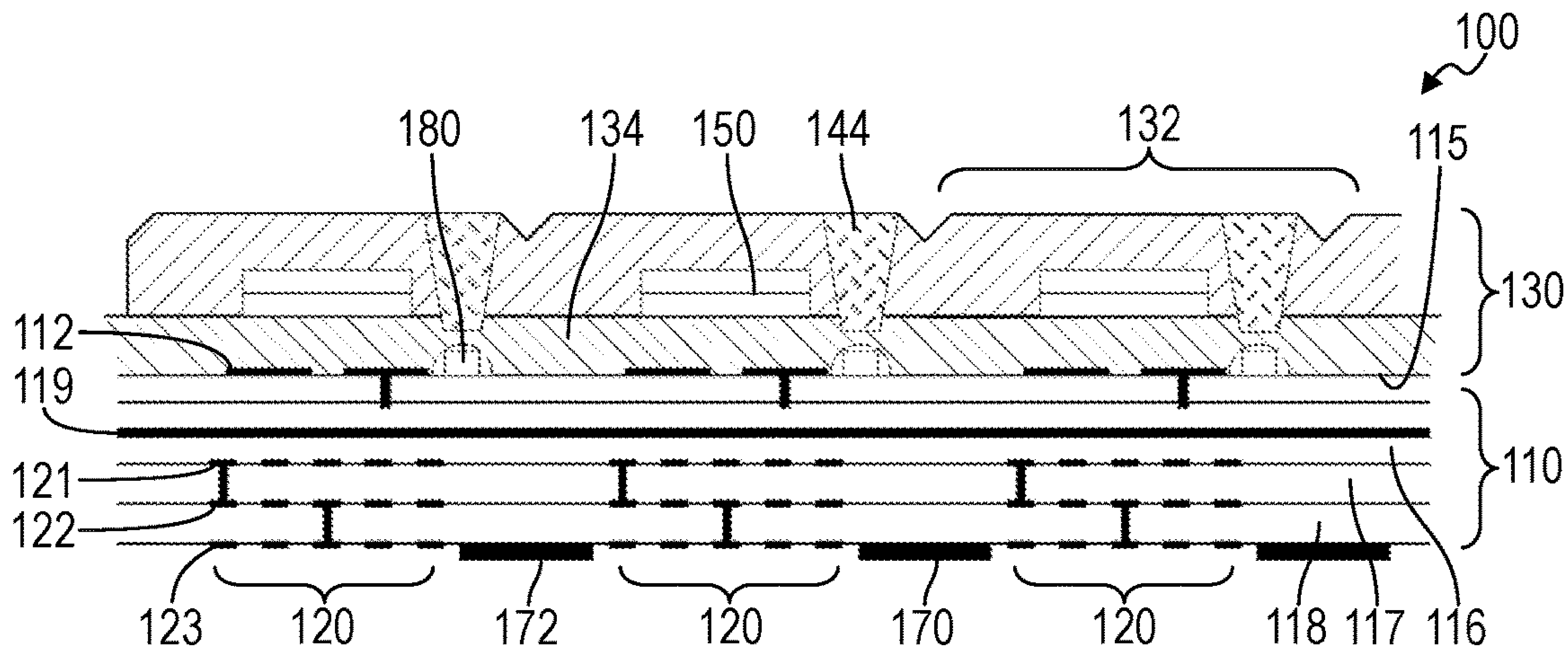

100
180
134
150
144
132
115
130
112
119
110
121
122
123
120
172
120
170
120
118
117
116

FIG. 5

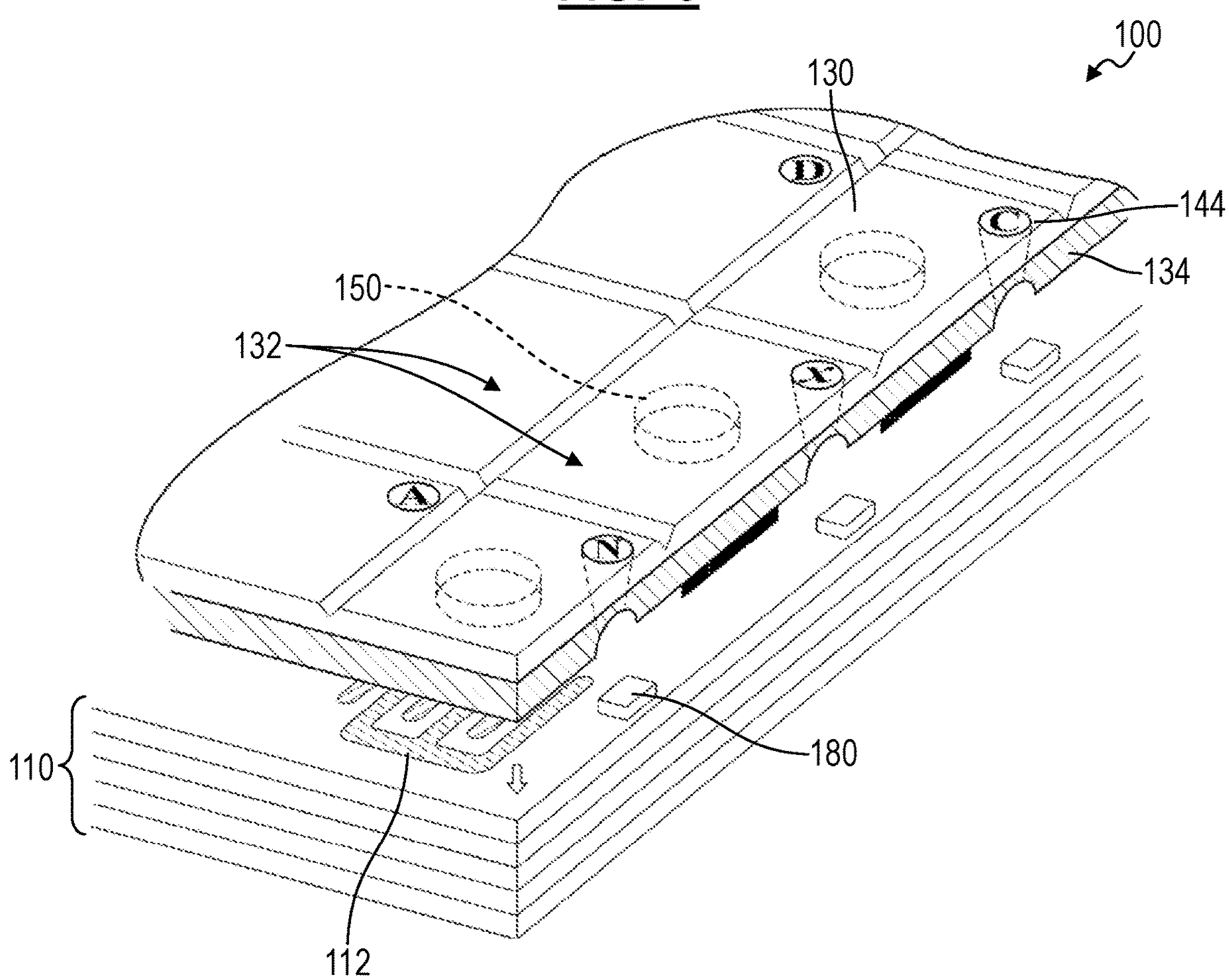

100
130
D
C
144
134
150
132
X
A
N
180
110
112

FIG. 6

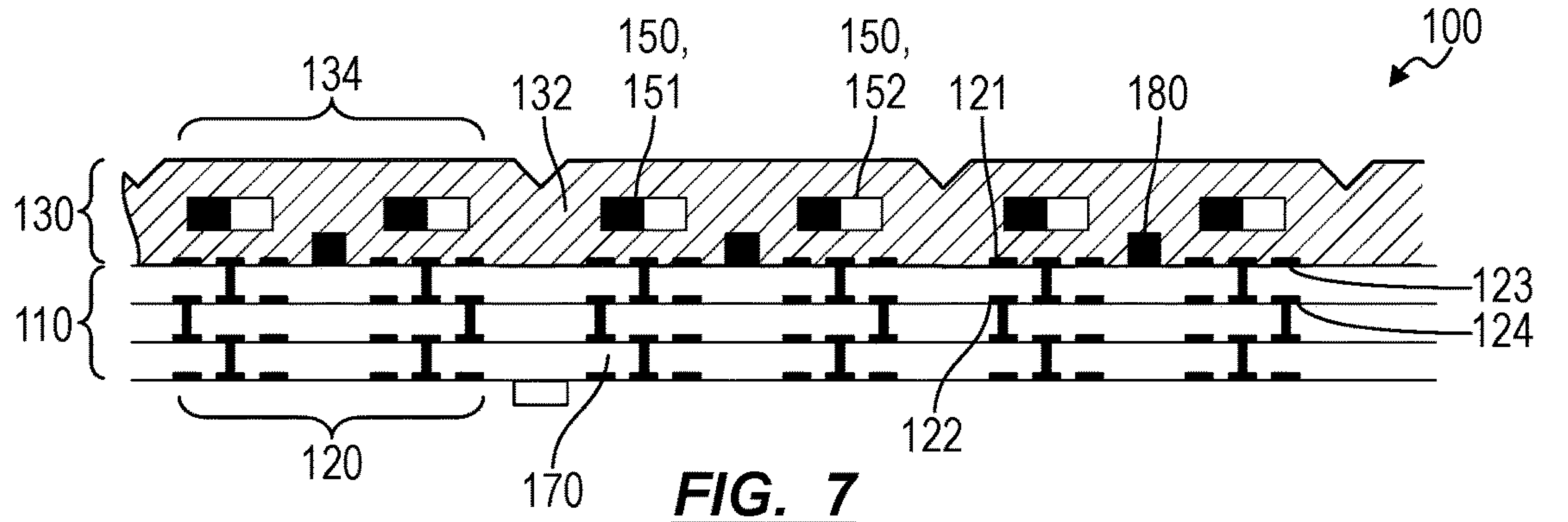

100
134
132
150, 151
150, 152
121
180
130
110
123
124
120
170
122

FIG. 7

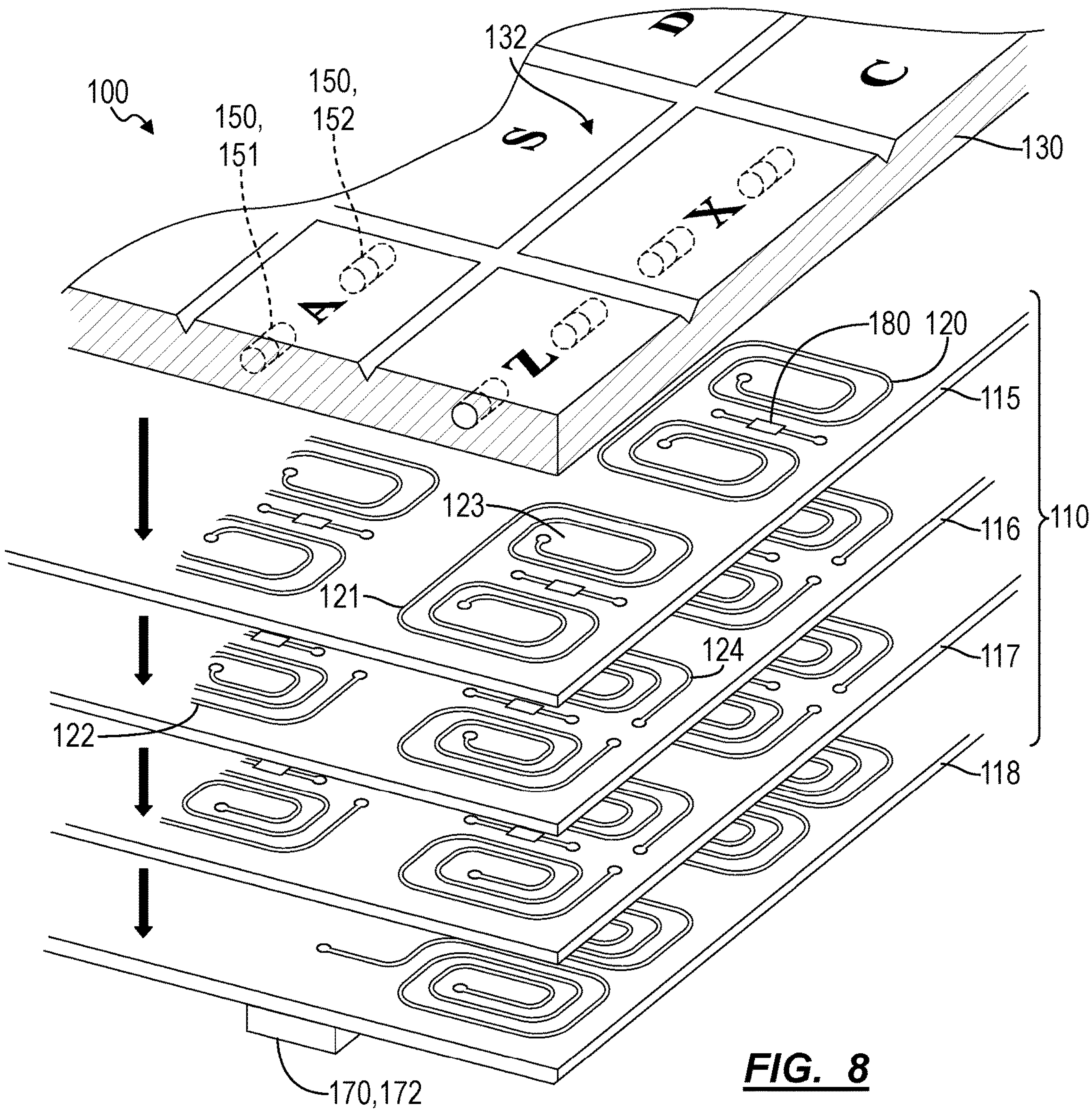
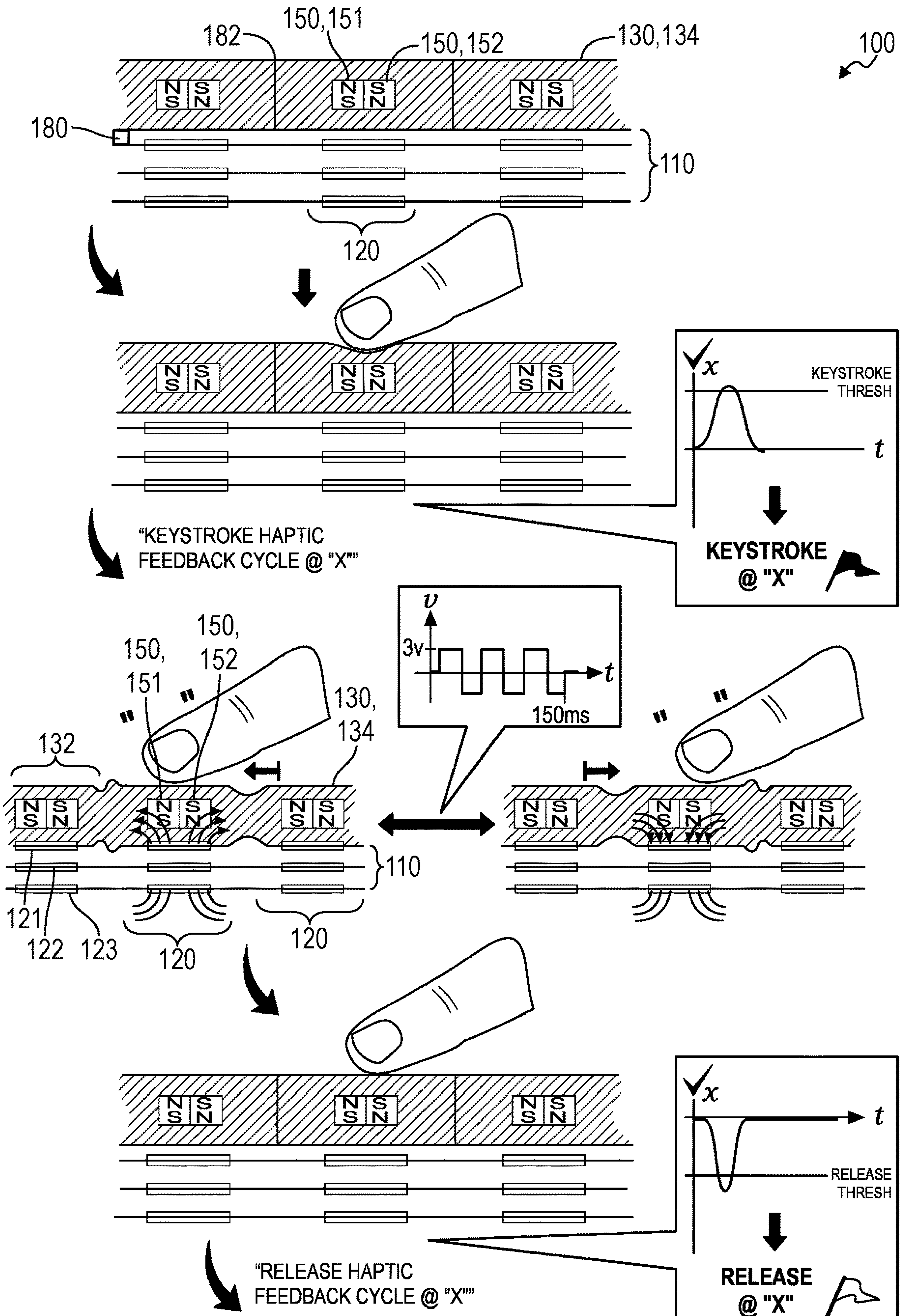

132
D
C
100
150, 152
150, 151
S
130
X
A
Z
180 120
115
123
116
110
121
124
117
122
118
170,172

FIG. 8



100
182
150,151
150,152
130,134
180
110
120
KEYSTROKE THRESH
KEYSTROKE @ "X"
"KEYSTROKE HAPTIC FEEDBACK CYCLE @ "X""
3v
150ms
150, 151
150, 152
130, 134
132
121
122
123
RELEASE THRESH
RELEASE @ "X"
"RELEASE HAPTIC FEEDBACK CYCLE @ "X""

FIG. 9

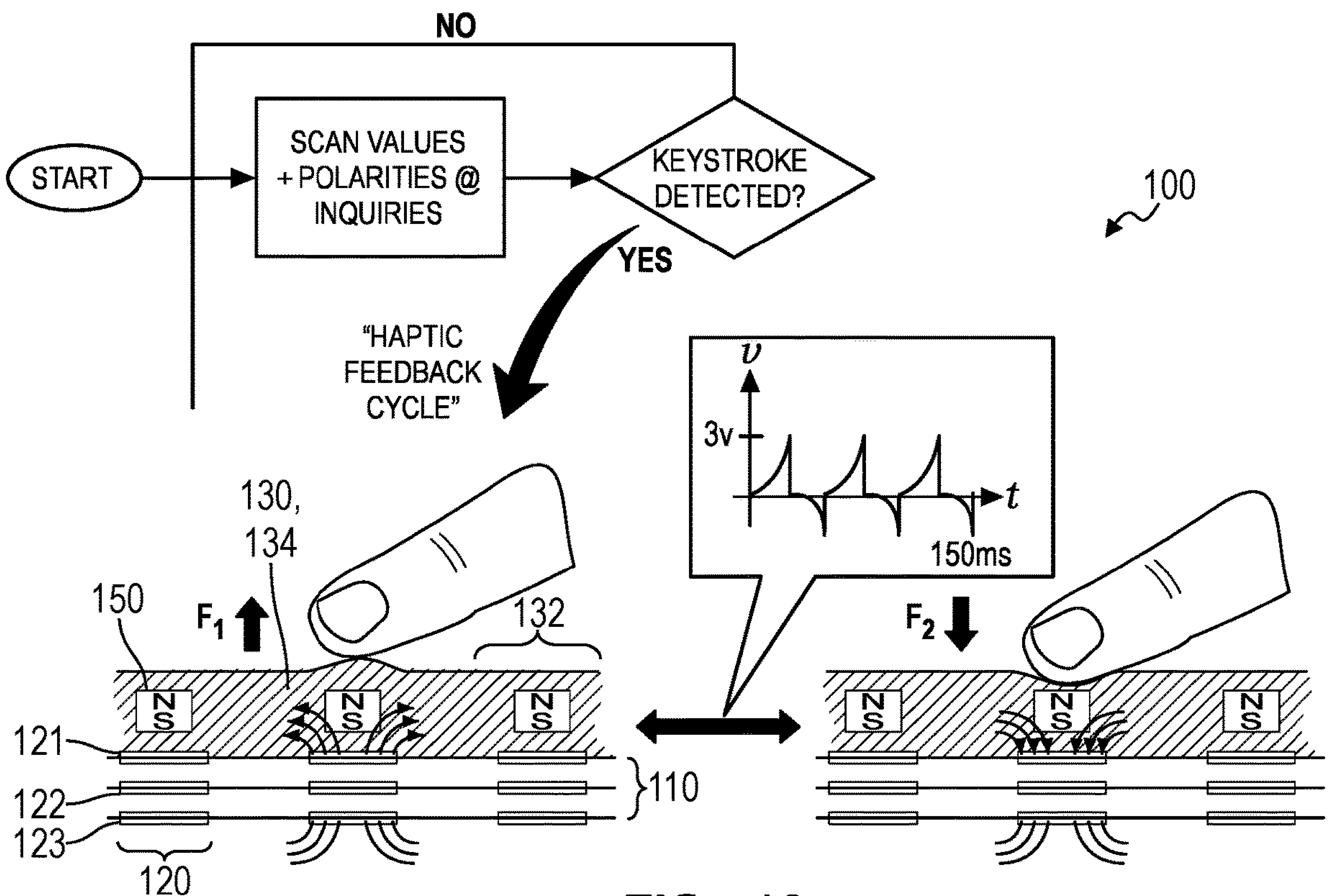

NO
START
SCAN VALUES + POLARITIES @ INQUIRIES
KEYSTROKE DETECTED?
YES
100
"HAPTIC FEEDBACK CYCLE"
v
3v
t
150ms
130, 134
150
F1
132
121
122
123
120
110
F2

FIG. 10

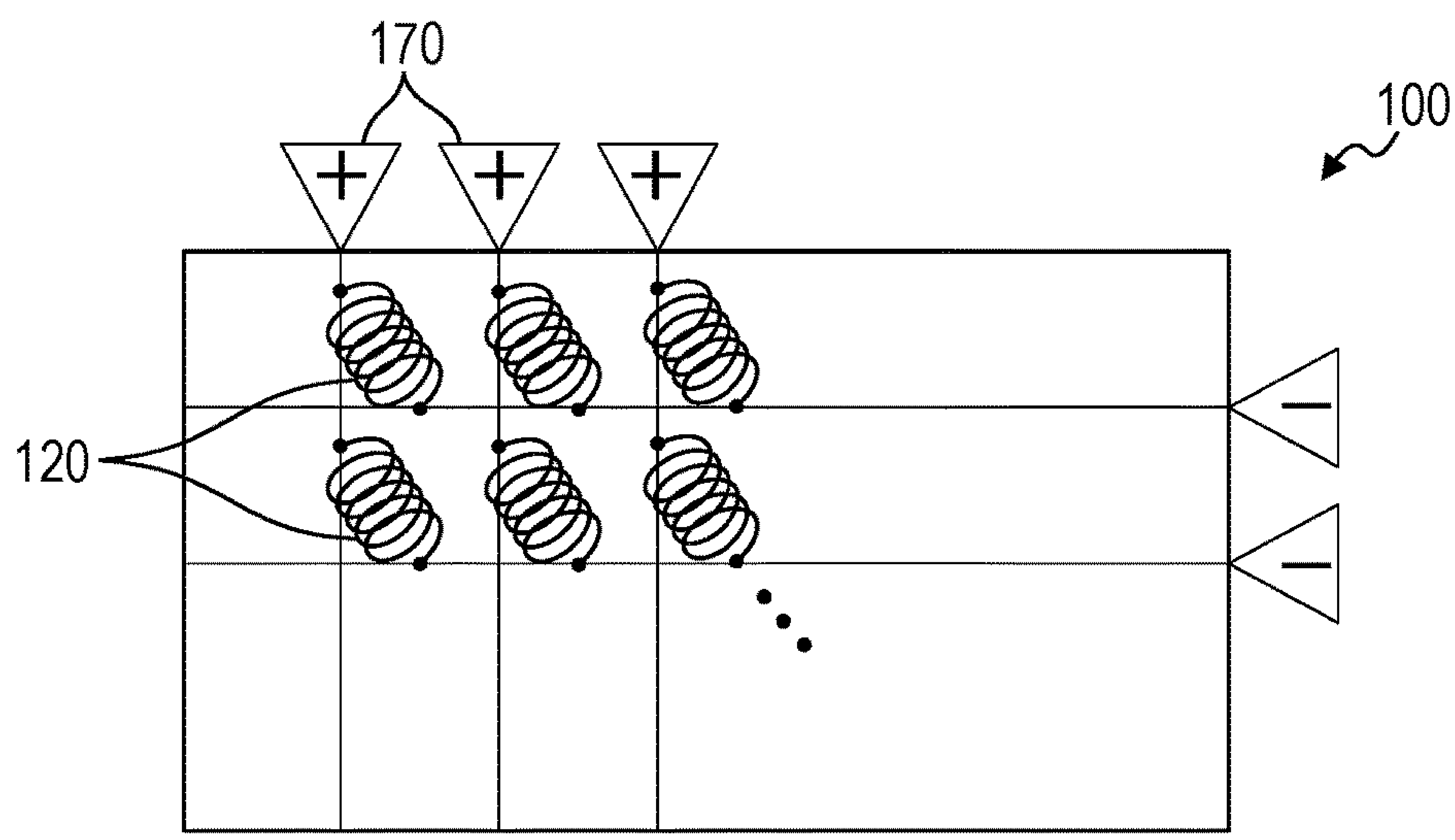

170
100
120

FIG. 11

HAPTIC KEYBOARD SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. 371 to International Application No. PCT/US21/53660, filed on 5 Oct. 2021, which claims priority to U.S. Provisional Patent Application 63/088,359, filed on 6 Oct. 2020, each of which is incorporated in its entirety by this reference.

This application is related to U.S. patent application Ser. No. 17/367,572, filed on 5 Jul. 2021, which is incorporated in its entirety by this reference.

TECHNICAL FIELD

This invention relates generally to the field of user input devices and more specifically to a new and useful keyboard system with key-level haptic feedback in the field of user input devices.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a schematic representation of a keyboard system;

FIG. **2** is a schematic representation of one variation of the keyboard system;

FIG. **3** is a schematic representation of one variation of the keyboard system;

FIG. **4** is a schematic representation of one variation of the keyboard system;

FIG. **5** is a schematic representation of one variation of the keyboard system;

FIG. **6** is a schematic representation of one variation of the keyboard system;

FIG. **7** is a schematic representation of one variation of the keyboard system;

FIG. **8** is a schematic representation of one variation of the keyboard system;

FIG. **9** is a flowchart representation of one variation of the keyboard system;

FIG. **10** is a flowchart representation of one variation of the keyboard system; and

FIG. **11** is a schematic representation of one variation of the keyboard system.

DESCRIPTION OF THE EMBODIMENTS

The following description of embodiments of the invention is not intended to limit the invention to these embodiments but rather to enable a person skilled in the art to make and use this invention. Variations, configurations, implementations, example implementations, and examples described herein are optional and are not exclusive to the variations, configurations, implementations, example implementations, and examples they describe. The invention described herein can include any and all permutations of these variations, configurations, implementations, example implementations, and examples.

1. Keyboard System

As shown in FIGS. **1-4**, a keyboard system **100** includes: a substrate **110**; a force-sensitive layer **160**; a set of keys; a set of coil drivers **171**; and a controller **170**. The substrate **110** includes: a substrate **110**; an array of drive electrode and sense electrode pairs **112** arranged across a top layer **115** of the substrate **110** at a set of key locations **132**; a set of multi-layer inductors **120** arranged across multiple layers of the substrate **110** at each key location **132** in the set of key locations **132**; and an inductor control circuit electrically coupling the set of multi-layer inductors **120** to the set of coil drivers **171**. The set of coil drivers **171** are configured to selectively polarize individual multi-layer inductors **120** in the set of multi-layer inductors **120**. The force-sensitive layer **160** is arranged over the substrate **110** adjacent the array of drive electrode and sense electrode pairs **112** and exhibits bulk change in local resistance as a function of applied force. The set of keys are arranged over the force-sensitive layer **160**. Each key in the set of keys: is arranged over the force-sensitive layer **160** in a key location **132**, in the set of key locations **132**, over an multi-layer inductor **120** in the set of multi-layer inductors **120**; includes a body; and includes a magnetic element **150** configured to magnetically couple to the multi-layer inductor **120** and to oscillate the body of the key responsive to polarization of the multi-layer inductor **120**.

The controller **170** is configured: to detect an input on a particular key in the set of keys responsive to a change in electrical value between a particular drive electrode and sense electrode pair **112** in the array of drive electrode and sense electrode pairs **112**; and to trigger a coil driver **171**, in the set of coil drivers **171**, to polarize a particular multi-layer inductor **120** proximal the particular key in response to the input.

One variation of the keyboard system **100** incudes: a substrate **110**; a tactile layer **130**; a force-sensitive layer **160**; an array of magnetic elements **150**; and a controller **170**. The substrate **110** includes: an array of electrodes; and an array of inductors **120** arranged below the array of electrodes. The tactile layer **130**: is arranged over the substrate **110**; and defines an array of key locations **132** over the array of inductors **120**. The force-sensitive layer **160** is interposed between the tactile layer **130** and the substrate and exhibits variations in local contact resistance across the array of electrodes responsive to variations in force applied to the tactile layer **130** at the array of key locations **132**. Each magnetic element **150** in the array of magnetic elements **150**: is arranged within the tactile layer **130** at a key location **132** in the array of key locations **132**; and is configured to inductively couple to an adjacent inductor **120** in the array of inductors **120**. The controller **170** is configured to read electrical values from the array of electrodes. The controller **170** is also configured to, at a first time and in response to detecting a change in electrical value at a first sense electrode, in the array of electrodes: register a first keystroke of a first key type associated with a first key location **132**, in the array of key locations **132**, defined over the first sense electrode; and drive an oscillating voltage across a first inductor **120**, arranged below the first sense electrode, during a first haptic feedback cycle to a) induce alternating magnetic coupling between the first inductor **120** and a first magnetic element **150**, in the array of magnetic elements **150**, arranged within the tactile layer **130** at the first key location **132** and b) oscillate the tactile layer **130**, at the first key location **132**, relative to the substrate **110**.

2. Applications

Generally, the keyboard system **100** functions as a computer keyboard (or keypad, or other typewriter-style device) including an independently-operated, non-mechanical haptic subsystem integrated into each individual key and configured to emulate mechanical "snap" buttons without sliding or rotating components and with minimal motion (e.g., 100 microns rather more than one millimeter).

In particular, the keyboard system **100** includes a single substrate **110** that contains: an array of drive electrode and sense electrode pairs **112** that cooperate with the force-sensitive layer **160** to form a touch sensor at each key location **132** of a keyboard layout; a set of multi-layer inductors **120** patterned across multiple layers of the substrate **110**—below the touch sensor—at each key location **132**; an inductor control circuit patterned across the substrate **110** and configured to distribute alternating current signals to individual inductors **120**; and a set of coil drivers **171** connected to the set of inductors **120** via the inductor control circuit and configured to energize individual inductors **120** via the inductor control circuit.

The force-sensitive layer **160** is arranged over the substrate **110** adjacent the touch sensor electrode array and exhibits bulk change in local resistance as a function of applied pressure such that application of a force yields a measurable change in electrical value (e.g., resistance) across an adjacent cluster of drive electrode and sense electrode pairs **112** in the force sensor.

The set of keys is arranged across the force-sensitive layer **160**, including one key located at each key location **132** and including a magnetic element **150** (e.g., a cylindrical magnet, an annular magnet, a Halbach array) configured to magnetically couple to the adjacent inductor **120** and thus oscillate the key relative to the substrate **110** when the adjacent inductor **120** is energized.

During a scan cycle, the controller **170** can: read a resistance value from each drive electrode and sense electrode pair **112**; interpret magnitudes forces (or pressures) applied to each drive electrode and sense electrode pair **112**—via the set of keys and the force-sensitive layer **160**—as a function of (e.g., inversely proportional to) resistance values read from these drive electrode and sense electrode pairs **112**; store these forces in a force image containing an array of pixels representing force magnitudes interpreted at corresponding drive electrode and sense electrode pairs **112**; detect a contiguous cluster of pixels in the force image exhibiting force magnitudes greater than a baseline force and/or contained within a boundary of a single key in the keyboard layout; and calculate a total force magnitude applied across this cluster of pixels. Then, if this total force magnitude applied across this cluster of pixels exceeds a threshold force (e.g., 160 grams), the controller **170** can: confirm a keystroke input at a particular key located over a cluster of drive electrode and sense electrode pairs **112** represented by the cluster of pixels in the force image; identify an inductor **120** address of an inductor **120** located below this particular key; identify and output a keystroke value (e.g., "a," "SHIFT") associated with this particular key; and trigger a coil driver **171** to output an alternating current to the inductor **120** address, thereby inducing magnetic coupling between the inductor **120** at the inductor **120** address and the magnetic element **150** in the particular key, oscillating the particular key during a "haptic feedback cycle," and emulating mechanical actuation of a mechanical key of a keyboard—such as within a 50-millisecond scan cycle.

The controller **170** can implement similar methods and techniques to detect concurrent keystroke inputs at multiple different keys (e.g., at "SHIFT" and "a" keys) during one scan cycle and can trigger the set of coil drivers **171** to selectively polarize inductors **120** at key locations **132** cospatial with these detected inputs, thereby individually and independently vibrating each of these keys to emulate concurrent mechanical actuation of these keys.

Therefore, the keyboard system **100** can enable independently-operable haptic feedback at each individual key within a keyboard layout without moving (i.e., rotating, sliding) components, thereby enabling the keyboard system **100** to include smaller, thinner, and/or lighter components without sacrificing durability and operating life. Furthermore, the keyboard system **100** can include a total quantity of discrete components that approaches the total quantity of keys in the keyboard layout—rather than multiples of this quantity of keys—thereby reducing cost, complexity, and failure modes for the keyboard system **100**. For example, the keyboard system **100** can include: a substrate **110** that includes a touch sensor electrode array, multi-layer inductors **120** for key-specific haptic feedback, an inductor control circuit, and coil drivers **171** in one singular assembly; a force-sensitive layer **160** that cooperates with the touch sensor electrode array to form a pressure-sensitive touch sensor; and one key at each key location **132** in the keyboard layout.

Furthermore, by locating all electrical components within one substrate **110** assembly below the force-sensitive layer **160** and eliminating mechanical actuation of keys, the keyboard system **100** can eliminate a thick frame around each key and thus enable each key to extend up to (e.g., within 50 microns) of the adjacent keys, thereby forming a nearly continuous keyboard surface and reducing or eliminating opportunity for dirt or other particulate to foul haptic operation of these key.

The keyboard system **100** is described herein as a keyboard (e.g., a QWERTY keyboard) integrated into a laptop computer or desktop keyboard peripheral. However, the keyboard system **100** can additionally or alternatively form a keypad or other button interface exhibiting key-specific haptic feedback that emulates tactile perception of mechanical "snap" buttons without moving mechanical components.

Generally, the system **100** is described herein as including an array of keys, each including a set of (i.e., one or more) magnetic elements that interface with one inductor to oscillate the key responsive to depression of the key. However, a key (e.g., a "spacebar") within the system **100** can be arranged over multiple discrete inductors and can include multiple sets of laterally-offset magnetic elements, each configured to interface with one inductor to (predominately) oscillate one region of the key, such as responsive to local depression of a corresponding region of the key or in response to an input that triggers the computing device to execute an action associated with the corresponding region of the key.

3. Independent Key Haptics

Generally, a magnetic element **150** integrated within a key and an inductor **120** integrated into the substrate **110** at a key location **132** below this key can cooperate to form a vibrator configured to oscillate the key relative to the substrate **110**.

3.1 Inductor

In particular, the inductor **120** can be formed by a set of planar coil traces etched or fabricated on each of multiple structural layers of the substrate **110** and interconnected by vias through these layers to form one continuous coil with multiple (e.g., many) turns below the magnetic element **150** integrated into the adjacent key.

For example, the inductor **120** can include: a first multi-loop trace spiraling inward in a first wind direction on a first, bottom layer of the substrate **110**; a second multi-loop trace spiraling outward in the first wind direction on a second layer **117** of the substrate **110**; a third multi-loop trace spiraling inward in the first wind direction on a third layer **118** of the substrate **110**; and a fourth multi-loop trace spiraling outward in the first wind direction—between adjacent loops of the second trace—on the second layer **117** of the substrate **110**. Vias can connect: the end of the first spiral trace in the first layer **116** to the start of the second spiral trace in the second layer **117**; the end of the second spiral trace in the second layer **117** to the start of the third spiral trace in the third layer **118**; the end of the third spiral trace in the third layer **118** to the start of the fourth spiral trace in the second layer **117**; and the end of the fourth spiral trace in the second layer **117** to the first, bottom layer near the start of the first spiral trace.

Thus, in this example, an inductor **120** can include multiple sets of spiral traces spanning multiple layers of the substrate **110** and connected to form a continuous, multi-loop coil with terminals of the inductor **120** falling in close proximity (e.g., within two millimeters) on the first, bottom layer of the substrate **110**.

3.2 Magnetic Element

The key can include a magnetic element **150** overmolded, bonded, or otherwise integrated into a body of the key (e.g., a molded silicone body) and can be arranged over the inductor **120** with the magnetic element **150** centered over the inductor **120**. The controller **170** can therefore trigger a coil driver **171** to supply an alternating current to the inductor **120**—such as via the inductor control circuit coupled to the inductor **120** and integrated into the substrate **110**—in order to induce an alternating magnetic field from the inductor **120** perpendicular to the touch sensor surface, thereby generating alternating magnetic coupling between the magnetic element **150** and the inductor **120** and thus oscillating the key relative to the substrate **110**, which a user touching the key with her finger may tactilely perceive and interpret as mechanical depression of the key.

3.3 Other Key and Inductor Pairs

The keyboard system **100** can include additional pairs of: inductors **120** integrated into the substrate **110**; and adjacent keys with integrated magnetic elements **150** to form a keyboard (or keypad, etc.) with discrete, independently-actuated haptic controls at each individual key.

4. Substrate

Generally, the substrate **110** includes a set of non-conductive structural layers interposed between a set of conductive layers patterned (e.g., etched) to form: an array of drive electrode and sense electrode pairs **112** of a touch sensor; a multi-layer inductive coil (hereinafter an "inductor **120**") below each key location **132** of the keyboard (or keypad, etc.); and an inductor control circuit connected to the set of multi-layer inductive coils. The substrate **110** also locates (or is connected to): a set of coil drivers **171** configured to selectively output alternating current to individual inductors **120**; and/or the controller **170**. For example, the substrate **110** can include a multi-layer printed circuit board (or "PCB") that includes—under each key location **132** of the keyboard—one drive electrode and sense electrode pair **112** fabricated on a top layer **115** of the substrate **110** and one inductor **120** fabricated from alternating spiral traces connected by vias in multiple layers of substrate **110**.

In particular, the drive electrode and sense electrode pairs **112**, multi-layer inductors **120**, and inductor control circuits (and lighting elements, etc.) can be fabricated across a single, multi-layer substrate **110** that both structurally supports the force-sensitive layer **160** and keys above, connects the array of drive electrode and sense electrode pairs **112** to the controller **170** for sampling and input detection, and distributes power to individual multi-layer inductors **120** during haptic feedback cycles. For example, the substrate **110** can be fabricated via multi-layer substrate **110** fabrication techniques; and the controller **170** coil drivers **171**, integrated circuits, light elements **180**, power and data connectors, and other circuit components can be soldered directly to the substrate **110** to complete all electronic and control assembly of the keyboard system **100** within this single substrate **110** assembly.

4.1 Drive and Sense Electrode Pairs

The array of sense electrode and drive electrode pairs are patterned across a top conductive layer of the substrate **110**. For example, and as described in U.S. patent application Ser. No. 14/499,001, the substrate **110** can include a grid of inter-digitated drive electrodes and sense electrodes patterned across its top conductive layer. In this example, rows of drive electrodes connected in series and columns of sense electrodes connected in series can be patterned across the top conductive layer of the substrate **110** to form an array of drive electrode and sense electrode pairs **112**.

The force-sensitive layer **160** is arranged over the substrate **110** and spans gaps between each drive electrode and sense electrode pair **112** such that, when a key is depressed, a local force is carried from the key into the force-sensitive layer **160**, which locally compresses the force-sensitive layer **160**, decreases the local resistance of the force-sensitive layer **160** below the key, and decreases the resistance across adjacent drive electrode and sense electrode pairs **112** on the substrate **110**. In particular, the resistance across these adjacent drive electrode and sense electrode pairs **112** may vary (e.g., drop) proportional (e.g., as a linear, inverse, or quadratic function) to the magnitude of the force applied to the key.

As described below, the controller **170** **160** can read resistance values across each drive electrode and sense electrode pair **112** and can interpret position and force magnitudes of inputs across the set of keys based on resistance values read from these drive electrode and sense electrode pairs **112**.

4.2 Inductor

In one implementation shown in FIGS. **1-4**, the keyboard system **100** includes a multi-layer substrate **110** that includes: a set of (e.g., six) conductive layers etched to form a suite of conductive traces; and a set of (e.g., five) structural layers interposed between the set of conductive layers. In this implementation, the substrate **110** includes a set of overlapping, interconnected spiral traces fabricated on a set of adjacent layers of the substrate **110** to form a single, multi-turn, multi-layer inductor **120** (that exhibits greater inductance and therefore greater magnetic coupling to an adjacent magnetic element **150** than a single spiral trace) at each key location **132**. The spiral traces within one inductor **120** can be coaxially aligned about a common vertical axis (e.g., centered below the adjacent key and magnetic element **150**) and electrically interconnected by a set of vias passing through the intervening structural layers of the substrate **110**.

In one example in which each inductor **120** spans an odd number of (e.g., 3, 5) conductive layers of the substrate **110**, the center conductive layers of this set of conductive layers can include pairs of concentric and offset spiral traces that both define starts on the outside of these spiral traces and ends near the center of these spiral traces (or vice versa) such that the end of the last spiral trace (i.e., a "second terminal") in the conductive layer "2" of the substrate **110** terminates near an outside of this last spiral trace—and near the start of the first spiral trace (i.e., a "first terminal) on the adjacent conductive layer "1" of the substrate **110**. In this example, in a substrate **110** that includes a three-layer inductor **120**, conductive layer "2" of the substrate **110** can include two concentric and offset spiral traces. Alternatively, in a substrate **110** that includes a five-layer inductor **120**, conductive layers "2," "3," and "4" of the substrate **110** can include two concentric and offset spiral traces.

Furthermore, conductive layers in the substrate **110** can exhibit different thicknesses. Accordingly, spiral traces fabricated on thicker conductive layers may exhibit narrow trace widths, and spiral traces fabricated on thinner conductive layers may exhibit wider trace widths in order to achieve similar electrical resistance across these spiral traces. Similarly, the lower conductive layers of the substrate **110** can include thicker (or "heavier") layers of conductive material (e.g., one-ounce copper approximately 35 microns in thickness) in order to accommodate narrow trace widths and more turns per unit area of spiral traces in these conductive layers, thereby increasing inductance of the spiral trace and increasing magnetic coupling of the inductor **120** to an adjacent magnetic element **150** during a haptic feedback cycle. Conversely, upper layers in the substrate **110**—which define sense and drive electrodes of the touch sensor—can include thinner layers of the conductive material.

4.3 Inductor Control Circuit and Coil Drivers

The substrate **110** also includes an inductor control circuit—such as patterned across the first (i.e., bottom) conductive layer—and extending to each inductor **120**. For example, the substrate **110** can include multiple (e.g., six) inductor **120** rows, wherein each inductor **120** row includes multiple inductors **120**. For each inductor **120** row, the inductor control circuit includes a row trace connecting first pins of each inductor **120** in this row in parallel. The inductor control circuit can also include a set of column traces, each connecting second pins of multiple inductors **120**—spanning multiple inductor **120** rows—in parallel. In particular, a column trace can connect the second pins of a group of inductors **120** in parallel, wherein this group of inductors **120** includes no more than one inductor **120** from each inductor **120** row.

Furthermore, the row and column traces can terminate at a set of coil driver **171** pads, such as on the first conductive layer of the substrate **110** opposite the force-sensitive layer **160**. A set of coil drivers **171** can be installed on these coil driver **171** pads, and each coil driver **171** can be configured to selectively energize one inductor **120** in the group of inductors **120** connected thereto by the inductor control circuit.

In one implementation, the inductor control circuit includes multiple row and column traces, wherein each pair of row and column traces connects first and second pins, respectively, of up to a limited quantity (e.g., four) inductors **120** to one coil driver **171**. In this implementation, one coil driver **171** can be connected to this limited quantity of inductors **120** located at key locations **132** characterized by low probability of concurrent selection by a user. For example, an "alphanumerical group" of inductors **120**—connected to one coil driver **171** via the inductor control circuit—can include one inductor **120** paired with a numerical key, two inductors **120** paired with alphabetical keys, and one inductor **120** paired with a "function" (e.g., "F1," . . . , "F12") key. The keyboard system **100** can thus include multiple (e.g., thirteen) similar alphanumerical inductor **120** groups, each connected to one coil driver **171**. In this example, a first "keyboard modifier group" of inductors **120**—connected to another coil driver **171** via the inductor control circuit—can include two inductors **120** paired with two "SHIFT" keys, one inductor **120** paired with a "CAPS LOCK" key, and one inductor **120** paired with an "escape" key. A second "keyboard modifier group" of inductors **120**—connected to yet another coil driver **171** via the inductor control circuit—can include two inductors **120** paired with two "COMMAND" keys and two inductors **120** paired with two punctuation keys. A third "keyboard modifier group" of inductors **120**—connected to another coil driver **171** via the inductor control circuit—can include two inductors **120** paired with two "OPTION" keys, one inductor **120** paired with a "POWER" key, and one inductor **120** paired with a punctuation key. A fourth "keyboard modifier group" of inductors **120**—connected to yet another coil driver **171** via the inductor control circuit—can include one inductor **120** paired with a "CONTROL" key, one inductor **120** paired with a "LINE RETURN" key, and one inductor **120** paired with a punctuation key. A fifth "keyboard modifier group" of inductors **120**—connected to another coil driver **171** via the inductor control circuit—can include one inductor **120** paired with a "DELETE" key, one inductor **120** paired with a "SPACEBAR" key, and two inductors **120** paired with two remaining punctuation keys. A sixth "navigation group" of inductors **120**—connected to another coil driver **171** via the inductor control circuit—can include four inductors **120** paired with each of four left, right, up, and down navigation keys.

The controller **170** can therefore initiate a haptic feedback cycle at a particular inductor **120** in the security technology—in response to depression of a corresponding key—by: selecting a particular coil driver **171** connected to a group of inductors **120** containing the particular inductor **120**; sending a particular address of the particular inductor **120** in this group to the particular coil driver **171**; and triggering the particular coil driver **171** to output an alternating signal to this particular address. Accordingly, the particular coil driver **171** can: connect a row trace coupled to the first pin of the particular inductor **120** to an alternating power source; connect a column trace coupled to the second pin of the particular inductor **120** to the alternating power source; and disconnect (or "float") all other row and column traces in the group in order to solely energize the particular inductor **120**, which thus magnetically couples to and oscillates the magnetic element **150** in the adjacent key.

However, inductors **120** in the set can be grouped according to any other schema, can be connected to one or more coil drivers **171** in any other format, and can be selectively polarized by the coil driver **171**(*s*) in any other way during a haptic feedback cycle.

5. Force-Sensitive Layer

As described above, the force-sensitive layer **160**: is arranged across the array of drive electrode and sense electrode pairs **112** on the top layer **115** of the substrate **110**; and defines a force-sensitive material exhibiting variations in local bulk resistance and/or local contact resistance as a function of compression between a key and the substrate **110**—and therefore as a function of force applied to a key arranged over the force-sensitive layer **160**. The force-sensitive layer **160** and the drive electrode and sense electrode pairs **112** on the top layer **115** of the substrate **110** can thus cooperate to form a touch sensor.

In one implementation, the perimeter of the force-sensitive layer **160** is retained against the substrate **110** via a frame and/or an adhesive. Additionally or alternatively, the force-sensitive layer **160** can be bonded to the substrate **110**, such as selectively at interstitial areas on the top surface of the substrate **110** between drive electrode and sense electrode pairs **112**. In another implementation, the force-sensitive layer **160** is mechanically retained against the substrate **110** near each key location **132** by retention posts **142** (or "shoulder pins") extending from each key through corresponding perforations in the force-sensitive layer **160** and the substrate **110**, as described below.

However, the force-sensitive layer **160** can be arranged over and coupled to the substrate **110** in any other way.

6. Keys

The keyboard system **100** can further include a set of discrete key elements **140** (or "keys"), each: arranged over the force-sensitive layer **160**; centered over an inductor **120** at a key location **132**; and including a magnetic element **150** configured to magnetically couple to the adjacent inductor **120**. Generally, the set of keys cooperate to from a tactile layer **130** that, when depressed by a user, returns local, key-specific haptic (e.g., vibratory) feedback to confirm keystrokes entered at individual keys.

6.1 Pinned Key Connection

In one implementation shown in FIGS. **1-3**, each key defines a discrete structure, including a rigid polymer (e.g., polycarbonate, nylon) overmolded around a magnetic element **150**. In this implementation, each discrete key can include: a top (i.e., outer) tactile surface; and a set of retention posts **142** (e.g., four shoulder pins including a narrow neck section and a widened head section) extending downward from the corners of the key opposite the tactile surface. In this implementation, the force-sensitive layer **160** defines a continuous layer extending across the top of the substrate **110**, and the substrate **110** and the force-sensitive layer **160** each include a set of (e.g., four) through-bores around the inductor **120** at each key location **132**. During assembly, the force-sensitive layer **160** is arranged over the substrate **110** with its through-bores aligned with corresponding through-bores in the substrate **110** at each key location **132**. The retention posts **142** of a key are then inserted through the through-bores in the force-sensitive layer **160** such that the heads of these shoulder pins engage the bottom surface of the substrate **110**, thereby retaining the key and the adjacent region of the force-sensitive layer **160** against the substrate **110**. Other keys in the set are similarly assembled onto the substrate **110** at each other key location **132** to form a complete keyboard.

6.1.1 Horizontal Magnetic Element Configuration

In the foregoing implementation, the magnetic element **150** in a key can be arranged in a horizontal orientation with N-S ends of the magnetic element **150** located proximal two opposing sides of the key, as shown in FIG. **3**. In this implementation, because a magnetic field generated by an inductor **120** passes through the center of the inductor **120** and thus normal to the top of the substrate **110**, this horizontal orientation of the magnetic element **150** in the key may cause the key to oscillate (predominantly) in a direction parallel to the top surface of the substrate **110**. Thus, in this implementation, the through-bores in the substrate **110** and force-sensitive layer **160** can be oversized for the neck sections of the retention posts **142** by a radial length approximating an oscillation amplitude of the key (e.g., 100 microns) such that pins can shift laterally within their bores with minimal obstruction as the key oscillates over the force-sensitive layer **160** when the corresponding inductor **120** is polarized during a haptic feedback cycle. Similarly, the perimeter of the key can be offset from the perimeters of adjacent keys by this oscillation amplitude, thereby enabling the key to oscillate without obstruction by these adjacent keys when the corresponding inductor **120** is polarized during a haptic feedback cycle.

Additionally or alternatively, in the foregoing implementation, elastic bumpers (e.g., low-durometer sleeves or grommets): can be installed in the through-bores in the substrate **110**; can deform to accommodate movement of the retention post **142** within these through-bores as the key oscillates during a haptic feedback cycle; and can re-center the key over its key location **132** following conclusion of the haptic feedback cycle. Alternatively, the through-bores in the substrate **110** can be oversized for the neck sections of the retention posts **142** as described above; and the force-sensitive layer **160** can include an elastic substrate **110** material, can include through-bores sized for a close (e.g., running) fit around the necks of the retention posts **142** of the key, and deform around these retention posts **142** when the key is oscillation during a haptic feedback cycle, and can re-center the key over the key location **132** following conclusion of the haptic feedback cycle.

Yet alternatively, in this implementation, a key can include a set of elastic retention posts **142**. For example, the body and retention posts **142** can be formed in an elastic material (e.g., silicone rubber) overmolded around the magnetic element **150**. In this implementation: the through-bores in the substrate **110** can be sized for a close (e.g., running) fit around the necks of the retention posts **142** of the key; the through-bores in the force-sensitive layer **160** can be sized for a loose fit around the necks of the retention posts **142** of the key; and the elastic retention posts **142** can elastically deform to accommodate oscillation of the key during a haptic feedback cycle.

6.1.2 Vertical Magnetic Element Configuration

Alternatively, the magnetic element **150** in a key can be arranged in a vertical orientation with N-S axis of the magnetic element **150** extending normal to the top surface of the substrate **110** and approximately centered over the corresponding inductor **120** at a key location **132**, as shown in FIG. **1**. In this implementation, because the magnetic field generated by the inductor **120** passes through the center of the inductor **120** and thus normal to the top of the substrate **110**, this vertical orientation of the magnetic element **150** in the key may cause the key to oscillate (predominantly) in a direction normal to the top surface of the substrate **110**.

Thus, in this implementation, a key can include a set of elastic retention posts **142**, such as described above, configured to elastically elongate in order to accommodate oscillation of the key during a haptic feedback cycle. Additionally or alternatively, these pins can extend rearward from the corners of the key, and the body of the key can be thin, elastic, and/or include a flexure that enables a center of the key containing the magnetic element **150** to oscillate vertically while the corners of the key are retained by the retention posts **142** and thus remain approximately static (e.g., exhibit less oscillation) during a haptic feedback cycle.

Alternatively, in this implementation: a key can include a pin with a head that extends below the bottom of the substrate **110** when installed through bores in the force-sensitive layer **160** and substrate **110** at a key location **132**; and a spring (e.g., a coil spring, an elastic grommet) can be installed between the head of the pin and the bottom surface of the substrate **110**. The spring can thus accommodate vertical oscillation of the key during a haptic feedback cycle; and draw the key downward toward the substrate **110** and retain the force-sensitive layer **160** against the substrate **110** following conclusion of a haptic feedback cycle.

6.2 Adhesive Key Integration

In another implementation, a discrete key can be bonded to the force-sensitive layer **160**, such as with a flexible adhesive that yields in shear to accommodate oscillation of the key relative to the force-sensitive layer **160** during a haptic feedback cycle.

In a similar implementation, the set of keys are molded into a single key assembly that includes flexures (or bellow or other structures configured to accommodate relative motion) between adjacent keys. In this implementation, regions of the key assembly between these keys can be bonded to the force-sensitive layer **160** or mechanically connected to the force-sensitive layer **160** and substrate **110**, such as via pinned connections as described above. Thus, in this implementation, these regions of the key assembly between keys can form a flexible "frame" around these keys, and the keys can oscillate individually within the frame during haptic feedback cycles.

6.3 Frame Integration

Alternatively, the keyboard system **100** can include a rigid frame (e.g., an aluminum frame): defining an aperture at each key location **132**; configured to install over the force-sensitive layer **160**; and configured to locate and retain each key over its key location **132**, as shown in FIG. **4**. In this implementation, a key can include a shoulder extending outwardly about the perimeter of its base, and the frame can retain this shoulder about the perimeter of the aperture housing the key.

In this implementation, for the key that includes a magnetic element **150** in the horizontal magnetic element **150** configuration, an aperture can also be oversized laterally for the body of the key above the shoulder—such as by the oscillation amplitude of the key—in order to enable the key to oscillate laterally during a haptic feedback cycle.

Conversely, for the key that includes a magnetic element **150** in the vertical magnetic element **150** configuration, the interior face of the frame around an aperture can be offset above the force-sensitive layer **160** by the sum of the thickness of the key shoulder and oscillation amplitude of the key in order to enable the key to oscillate vertically during a haptic feedback cycle. (In this implementation, the keyboard system **100** can also include a spring between the key and the frame in order to bias the key against the force-sensitive layer **160** or between the key and the force-sensitive layer **160** in order to bias the key against the frame while also enabling the key to oscillation vertically during a haptic feedback cycle.)

However, a key can be coupled to and retained over the force-sensitive layer **160** and substrate **110** in any other way.

7. Illumination

In one variation shown in FIGS. **1-4**, the substrate **110** further includes an array of light elements **180** (e.g., LEDs), including one light element **180** at each key location **132**, configured to illuminate the set of keys.

In one implementation, the top of the substrate **110** is relieved proximal the center of the inductor **120** at each key location **132** to form a recess and expose the second conductive layer (over the first structural layer of the substrate **110**) in the recess. In particular, each recess can be sized for a surface-mount LED, and the second conductive layer of the substrate **110** can include pads configured to mount the surface-mount LED. During assembly, surface-mount LEDs can be installed in each recess and soldered to the pads within these recesses such that the top of the light element **180** is flush with or falls below the top surface of the substrate **110**. Furthermore, in this implementation, the force-sensitive layer **160** can form a translucent structure (e.g., translucent silicone rubber supporting a matrix of conductive particulate). Similarly, each key can be formed in a translucent material or include a light pipe **182** aligned with the light element **180** such that light passing through the force-sensitive layer **160** illuminates the key (similar to as shown in FIG. **9**).

In another implementation shown in FIGS. **3** and **4**, a surface mount LED is installed on the top conductive layer of the substrate **110** at each key location **132**, such as approximately centered over a corresponding inductor **120**. In this implementation, the force-sensitive layer **160** is perforated at each LED location, and each key is formed in a translucent material or includes a light pipe **182** aligned with the light element **180** (e.g., through a center of the magnetic element **150** defining an annular magnet) such that light emitted by the light element **180** illuminates the top of the key.

In yet another implementation, the substrate **110** and force-sensitive layer **160** are perforated at each key location **132**, such as with one or a set of perforations located inside of the spiral traces formed by the inductor **120** at each key location **132**. In this implementation, a light source is arranged across or near the bottom face of the substrate **110**, such as including one light element **180** per key location **132** or cluster of key locations **132**. In this implementation, each key can be formed in a translucent material or include a light pipe **182** aligned with an adjacent perforation in the force-sensitive layer **160** and substrate **110** such that light output below the substrate **110** passed through the substrate **110** and force-sensitive layer **160** to illuminate the key.

In a similar implementation shown in FIGS. **1** and **2**, in the variation described above in which a key includes a set of pins that pass through the substrate **110** and the force-sensitive layer **160**, the pins can be formed in a translucent material to form light pipes **182**, and a light source can be arranged across the bottom face of the substrate **110**. Thus, the pins of this key can transmit light—emitted by this light source—through the substrate **110** and force-sensitive layer **160** to illuminate the key.

However, the keyboard system **100** can include any other key and light source configuration to illuminate these keys.

8. Chassis Installation

The substrate **110**—overlayed with the force-sensitive layer **160** and keys—can be installed in a keyboard receptacle of a computing device, such as by rigidly fastening or bonding the perimeter of the substrate **110** to a perimeter of the receptacle.

However, the substrate **110** can be installed or mounted to a chassis in any other way.

9. Controller

The controller **170** is configured to: scan electrical values (e.g., resistances) between drive electrode and sense electrode pairs **112** in the substrate **110**; interpret a force magnitude and a location of an input across the set of keys based on changes in electrical values between a subset of these drive electrode and sense electrode pairs **112**; interpret a keystroke value corresponding to a particular key proximal the location of this input and output this keystroke value (e.g., to a connected computer) if the force magnitude of the input exceeds a threshold force magnitude; and trigger a coil driver **171** to output an alternating current to a particular inductor **120** adjacent the particular key in order to vibrate the particular key—such as for a period of 100 milliseconds beginning within 10 milliseconds of detecting the input at the particular key—during a haptic feedback cycle. A user depressing the particular key with a finger may thus tactilely perceive resulting oscillation of the particular key as depression of the particular key—similar to a mechanical "snap" button—below her finger.

More specifically and as described above, the substrate **110** can include a drive electrode and sense electrode pair **112** below each key of the keyboard; and the force-sensitive layer **160** can be arranged between the substrate **110** and the set of keys, can bridge gaps between these drive electrode and sense electrode pairs **112**, and can exhibit variable resistance between each drive electrode and sense electrode pair **112** as a function of downward force applied to the corresponding key. For example, depression of a particular key can compress a particular region of the force-sensitive layer **160** under the key against the particular drive electrode and sense electrode pair **112** located under this key, thereby reducing the resistance between the particular drive electrode and sense electrode pair **112**—bridged by this region of the force-sensitive layer **160**—and increasing the voltage at the sense electrode when the drive electrode is driven to a reference or nominal voltage.

Thus, during a scan cycle, the controller **170** can read electrical values from the array of electrodes by: driving these drive electrodes with a reference voltage; and reading sense voltages from these sense electrodes. The controller **170** can then register a keystroke on a first key during this scan cycle in response to a first sense voltage—read from a first sense electrode—differing from a stored baseline voltage for the first sense electrode, such as by more than a first threshold voltage that corresponds to a minimum keystroke force assigned to the first key (e.g., 165 grams). Accordingly, the controller **170** can execute a first haptic feedback cycle at the first key by driving a first inductor **120**—located under the first key—with an oscillating voltage, thereby: causing the first inductor **120** to generate an oscillating magnetic field, which interacts with and oscillates a first magnetic element **150** in the first key independently of all other keys within the keyboard; and haptically indicates to a user that the controller **170** registered a keystroke at the first key.

Then, during a later (e.g., a next) scan cycle), the controller **170** can: drive the drive electrodes at each key location **132** with a reference voltage; read a second set of sense voltages (i.e., "electrical values") from these sense electrodes; and register release of the first keystroke from the first key in response to a second sense voltage—read from the first sense electrode during the second scan cycle—differing from the stored baseline voltage for the first sense electrode by less than a second threshold voltage, such as less than the first threshold voltage. Accordingly, the controller **170** can execute a second haptic feedback cycle at the first key by driving the first inductor **120**—located under the first key—with an oscillating voltage, thereby: again causing the first inductor **120** to generate an oscillating magnetic field, which interacts with and oscillates the first magnetic element **150** in the first key independently of all other keys within the keyboard; and haptically indicates to the user that the controller **170** registered a release of the first key.

In particular, the controller **170** can implement different threshold electrical value changes to detect selection and release of these keys in order to avoid repetitive haptic feedback cycles (or "bounce," "jitter") at keys when a user depresses these keys with consistent forces around the minimum keystroke forces assigned to these keys. For example, the controller **170** can: implement a first threshold electrical value change—corresponding to a minimum keystroke force of 165 grams—to detect selection of keys in the keyboard; and then drive inductors **120** corresponding to these keys with oscillating signals of a first amplitude and a second frequency that generates key vibration physically or tactilely analogous to collapse of a mechanical dome switch or mechanical key. In this example, the controller **170** can also: implement a second threshold electrical value change—less than the first threshold electrical value change and corresponding to a maximum key release force of 100 grams—to detect release of keys in the keyboard; and then drive inductors **120** corresponding to these keys with oscillating signals of a second amplitude and frequency (e.g., less than the first amplitude and greater than the first frequency) and that generates key vibration physically or tactilely analogous to rise of a mechanical dome switch or mechanical key.

9.1 Selective Keystroke Sensing

Furthermore, because polarization of an inductor **120** may induce electrical noise in an adjacent drive electrode and sense electrode pair **112**, the controller **170** can also selectively skip or disable sampling of a particular drive electrode and sense electrode pair **112** arranged over the inductor **120** (and/or particular row and column traces coupled to the particular drive electrode and sense electrode pair **112**) during and immediately after the haptic feedback cycle (e.g., as the particular inductor **120** depth sensor-energizes). Additionally or alternatively, the controller **170** can continue to sample all drive electrode and sense electrode pairs **112** in the touch sensor during the haptic feedback cycle but discard all additional inputs interpreted at the particular drive electrode and sense electrode pair **112** during and immediately after the haptic feedback cycle. Yet alternatively, the controller **170** can continue to sample all drive electrode and sense electrode pairs **112** in the touch sensor during the haptic feedback cycle but increase a threshold force for interpreting an input at the particular drive electrode and sense electrode pair **112** in order to reduce sensitivity to noise at the particular drive electrode and sense electrode pair **112** during and immediately after the haptic feedback cycle.

10. Multi-Layer Inductor

As described above and shown in FIGS. **2** and **8**, the keyboard system includes a multi-layer inductor **120**—formed by a set of interconnected spiral traces fabricated directly within conductive layers within the substrate **110**—under each key location **132**.

Generally, the total inductance of a single spiral trace may be limited by the thickness of the conductive layer. Therefore, the keyboard system can include a stack of overlapping, interconnected spiral traces fabricated on a set of adjacent layers of the substrate **110** to form a multi-layer, multi-turn, and/or multi-core inductor **120** that exhibits greater inductance—and therefore greater magnetic coupling to the set of magnetic elements **150**—than a single spiral trace on a single conductive layer of the substrate **110**. These spiral traces can be coaxially aligned about a common vertical axis (e.g., centered over the set of magnetic elements **150**) and electrically interconnected by a set of vias through the intervening layers of the substrate **110**.

Furthermore, the substrate **110** can include conductive layers of different thicknesses. Accordingly, spiral traces within thicker conductive layers of the substrate **110** can be fabricated with narrower trace widths and more turns, and spiral traces within thinner conductive layers of the substrate **110** can be fabricated with wider trace widths and fewer turns in order to achieve similar electrical resistances within each spiral trace over the same coil footprint. For example, lower conductive layers within the substrate **110** can include heavier layers of conductive material (e.g., one-ounce copper approximately 35 microns in thickness) in order to accommodate narrower trace widths and more turns within the coil footprint in these conductive layers, thereby increasing inductance of each spiral trace and yielding greater magnetic coupling between the multi-layer inductor **120** and the set of magnetic elements **150** during a haptic feedback cycle. Conversely, in this example, the upper layers of the substrate **110**—which include drive electrode and sense electrode pairs **112** of the touch sensor—can include thinner layers of conductive material.

10.1 Single Core+Even Quantity of Coil Layers

In one implementation, the substrate **110** includes an even quantity of spiral traces fabricated within an even quantity of layers within the substrate **110** to form a single-coil inductor **120** under a key of the keyboard.

In one example, the substrate **110** includes: a top layer **115** and an intermediate layer containing the array of drive electrode and sense electrode pairs **112**; a first layer **116**; a second layer **117**; a third layer **118**; and a fourth (e.g., a bottom) layer. In this example, the first layer **116** includes a first spiral trace **121** coiled in a first direction and defining a first end and a second end. In particular, the first spiral trace **121** can define a first planar coil spiraling inwardly in a clockwise direction from the first end at the periphery of the first planar coil to the second end proximal a center of the first planar coil. The second layer **117** includes a second spiral trace **122** coiled in a second direction opposite the first direction and defining a third end—electrically coupled to the second end of the first spiral trace **121**—and a fourth end. In particular, the second spiral trace **122** can define a second planar coil spiraling outwardly in the clockwise direction from the third end proximal the center of the second planar coil to the fourth end at a periphery of the second planar coil.

Similarly, the third layer **118** includes a third spiral trace **123** coiled in the first direction and defining a fifth end—electrically coupled to the fourth end of the second spiral trace **122**—and a sixth end. In particular, the third spiral trace **123** can define a third planar coil spiraling inwardly in the clockwise direction from the fifth end at the periphery of the third planar coil to the sixth end proximal a center of the third planar coil. Furthermore, the fourth layer includes a fourth spiral trace **124** coiled in the second direction and defining a seventh end—electrically coupled to the sixth end of the first spiral trace **121**—and an eighth end. In particular, the fourth spiral trace **124** can define a fourth planar coil spiraling outwardly in the clockwise direction from the seventh end proximal the center of the fourth planar coil to the eighth end at a periphery of the fourth planar coil.

Accordingly: the second end of the first spiral trace **121** can be coupled to the third end of the second spiral trace **122** by a first via; the fourth end of the second spiral trace **122** can be coupled to the fifth end of the third spiral trace **123** by a second via; the sixth end of the third spiral trace **123** can be coupled to the seventh end of the fourth spiral trace **124** by a third via; and the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** can cooperate to form a single-core, four-layer inductor **120**. The controller **170** (or a driver): can be electrically connected to the first end of the first spiral trace **121** and the eighth end of the fourth spiral trace **124** (or "terminals" of the multi-layer inductor **120**); and can drive these terminals of the multi-layer inductor **120** with an oscillating voltage during a haptic feedback cycle in order to induce an alternating magnetic field through the multi-layer inductor **120**, which couples to the magnetic element **150** in the key (or tactile layer **130**) above and oscillates the key (or a local region of the tactile layer **130**) over the substrate **110**. In particular, when the controller **170** drives the multi-layer inductor **120** at a first polarity, current can flow in a continuous, clockwise direction through the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** to induce a magnetic field in a first direction around the multi-layer inductor **120**. When the controller **170** reverses the polarity across terminals of the multi-layer inductor **120**, current can reverse directions and flow in a continuous, counter-clockwise direction through the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** to induce a magnetic field in a second, opposite direction at the multi-layer inductor **120**.

Furthermore, in this implementation, because the multi-layer inductor **120** spans an even quantity of conductive layers within the substrate **110**, the terminals of the multi-layer inductor **120** can be located on the peripheries of the first and last layers of the substrate **110** and thus enable direct connection to the controller **170** (or other driver).

10.2 Single Core+Odd Quantity of Coil Layers

In another implementation shown in FIG. **2**, the multi-layer inductor **120** spans an odd number of (e.g., 3, 5) conductive layers of the substrate **110**. In this implementation, a conductive layer of the substrate **110** can include two parallel and offset spiral traces that cooperate with other spiral traces in the multi-layer inductor **120** to locate the terminals of the multi-layer inductor **120** at the periphery of the multi-layer inductor **120** for direct connection to the controller **170** or driver.

In one example, the substrate **110** includes: a top layer **115** and an intermediate layer containing the array of drive electrode and sense electrode pairs **112**; a first layer **116**; a second layer **117**; a third layer **118**; and a fourth (e.g., a bottom) layer. In this example, the first layer **116** includes a ground electrode **119** (e.g., a continuous trace): spanning the footprint of the array of drive electrode and sense electrode pairs **112** in the top and intermediate layers; driven to a reference potential by the controller **170**; and configured to shield the drive electrode and sense electrode pair **112** at each key location **132** from electrical noise generated by the adjacent multi-layer inductors **120**.

In this example, the third layer **118** includes a first spiral trace **121** coiled in a first direction and defining a first end and a second end. In particular, the first spiral trace **121** can define a first planar coil spiraling inwardly in a clockwise direction from the first end at the periphery of the first planar coil to the second end proximal a center of the first planar coil. The second layer **117** includes a second spiral trace **122** coiled in a second direction opposite the first direction and defining a third end—electrically coupled to the second end of the first spiral trace **121** in the third layer **118**—and a fourth end. In particular, the second spiral trace **122** can define a second planar coil spiraling outwardly in the clockwise direction from the third end proximal the center of the second planar coil to the fourth end at a periphery of the second planar coil.

The third layer **118** further includes a third spiral trace **123** coiled in the first direction and defining a fifth end—electrically coupled to the fourth end of the second spiral trace **122** in the second layer **117**—and a sixth end. In particular, the third spiral trace **123** can define a third planar coil: spiraling inwardly in the clockwise direction from the fifth end at the periphery of the third planar coil to the sixth end proximal a center of the third planar coil; and nested within the first planar coil that also spirals inwardly in the clockwise direction within the third layer **118**.

Furthermore, the fourth layer includes a fourth spiral trace **124** coiled in the second direction and defining a seventh end—electrically coupled to the sixth end of the first spiral trace **121**—and an eighth end. In particular, the fourth spiral trace **124** can define a fourth planar coil spiraling outwardly in the clockwise direction from the seventh end proximal the center of the fourth planar coil to the eighth end at a periphery of the fourth planar coil.

Accordingly: the second end of the first spiral trace **121** within the third layer **118** can be coupled to the third end of the second spiral trace **122** within the second layer **117** by a first via; the fourth end of the second spiral trace **122** within the second layer **117** can be coupled to the fifth end of the third spiral trace **123** within the third layer **118** by a second via; the sixth end of the third spiral trace **123** within the third layer **118** can be coupled to the seventh end of the fourth spiral trace **124** within the fourth layer by a third via; and the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** can cooperate to form a single-core, three-layer inductor **120**. The controller **170**: can be electrically connected to the first end of the first spiral trace **121** within the third layer **118** and the eight end of the fourth spiral trace **124** within the fourth layer (or "terminals" of the multi-layer inductor **120**); and can drive these terminals of the multi-layer inductor **120** with an oscillating voltage during a haptic feedback cycle in order to induce an alternating magnetic field through the multi-layer inductor **120**, which couples to the magnetic element **150** in the key (or tactile layer **130**) above and oscillates the key (or a local region of the tactile layer **130**) over the substrate **110**. In particular, when the controller **170** drives the multi-layer inductor **120** at a first polarity, current can flow in a continuous, clockwise direction through the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** within the second, third, and fourth layers of the substrate **110** to induce a magnetic field in a first direction around the multi-layer inductor **120**. When the controller **170** reverses the polarity across terminals of the multi-layer inductor **120**, current can reverse directions and flow in a continuous, counter-clockwise direction through the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** to induce a magnetic field in a second, opposite direction at the multi-layer inductor **120**.

Therefore, in this implementation, the substrate **110** can include an even number of single-coil layers and an odd number of two-coil layers selectively connected to form a multi-layer inductor **120** that includes two terminals located on the periphery of the multi-layer inductor **120** at each key location **132**.

10.3 Double Core+Even Quantity of Coil Layers

In another implementation shown in FIG. **8**, the substrate **110** includes an even quantity of spiral traces fabricated within an even quantity of layers within the substrate **110** to form a dual-core inductor **120** (that is, two separate single-core inductors **120** connected in series).

In one example, the substrate **110** includes: a top layer **115** and an intermediate layer containing the array of drive electrode and sense electrode pairs **112**; a first layer **116**; a second layer **117**; a third layer **118**; and a fourth (e.g., a bottom) layer.

In this example, the first layer **116** includes a first spiral trace **121** coiled in a first direction and defining a first end and a second end. In particular, the first spiral trace **121** can define a first planar coil spiraling inwardly in a clockwise direction from the first end at the periphery of the first planar coil to the second end proximal a center of the first planar coil. The second layer **117** includes a second spiral trace **122** coiled in a second direction opposite the first direction and defining a third end—electrically coupled to the second end of the first spiral trace **121**—and a fourth end. In particular, the second spiral trace **122** can define a second planar coil spiraling outwardly in the clockwise direction from the third end proximal the center of the second planar coil to the fourth end at a periphery of the second planar coil. The third layer **118** includes a third spiral trace **123** coiled in the first direction and defining a fifth end—electrically coupled to the fourth end of the second spiral trace **122**—and a sixth end. In particular, the third spiral trace **123** can define a third planar coil spiraling inwardly in the clockwise direction from the fifth end at the periphery of the third planar coil to the sixth end proximal a center of the third planar coil. Furthermore, the fourth layer includes a fourth spiral trace **124** coiled in the second direction and defining a seventh end—electrically coupled to the sixth end of the first spiral trace **121**—and an eighth end. In particular, the fourth spiral trace **124** can define a fourth planar coil spiraling outwardly in the clockwise direction from the seventh end proximal the center of the fourth planar coil to the eighth end at a periphery of the fourth planar coil.

Accordingly: the second end of the first spiral trace **121** can be coupled to the third end of the second spiral trace **122** by a first via; the fourth end of the second spiral trace **122** can be coupled to the fifth end of the third spiral trace **123** by a second via; the sixth end of the third spiral trace **123** can be coupled to the seventh end of the fourth spiral trace **124** by a third via; and the first, second, third, and fourth spiral traces **121**, **122**, **123**, **124** can cooperate to form a first single-core, four-layer inductor **120**.

Furthermore, in this example, the first layer **116** includes a fifth spiral trace adjacent the first spiral trace **121**, coiled in the second direction, and defining a ninth end—coupled to the first end of the first planar coil—and a tenth end. In particular, the fifth spiral trace can define a fifth planar coil spiraling inwardly in a clockwise direction from the ninth end at the periphery of the fifth planar coil to the tenth end proximal a center of the fifth planar coil. The second layer **117** includes a sixth spiral trace adjacent the second spiral trace **122**, coiled in the first direction, and defining an eleventh end—electrically coupled to the tenth end of the fifth spiral trace—and a twelfth end. In particular, the sixth spiral trace can define a sixth planar coil spiraling outwardly in the clockwise direction from the eleventh end proximal the center of the sixth planar coil to the twelfth end at a periphery of the sixth planar coil. The third layer **118** includes a seventh spiral trace adjacent the third spiral trace **123**, coiled in the second direction, and defining a thirteenth end—electrically coupled to the twelfth end of the sixth spiral trace—and a fourteenth end. In particular, the seventh spiral trace can define a seventh planar coil spiraling inwardly in the clockwise direction from the thirteenth end at the periphery of the seventh planar coil to the fourteenth end proximal a center of the seventh planar coil. Furthermore, the fourth layer includes an eighth spiral trace adjacent the fourth spiral trace **124**, coiled in the first direction, and defining a fifteenth end—electrically coupled to the fourteenth end of the seventh spiral trace—and a sixteenth end. In particular, the eighth spiral trace can define an eighth planar coil spiraling outwardly in the clockwise direction from the fifteenth end proximal the center of the eighth planar coil to the sixteenth end at a periphery of the eighth planar coil.

Accordingly: the tenth end of the fifth spiral trace can be coupled to the eleventh end of the sixth spiral trace by a fourth via; the twelfth end of the sixth spiral trace can be coupled to the thirteenth end of the seventh spiral trace by a fifth via; the fourteenth end of the seventh spiral trace can be coupled to the fifteenth end of the eighth spiral trace by a sixth via; and the fifth, sixth, seventh, and eighth spiral traces can cooperate to form a second single-core, four-layer inductor **120**.

Furthermore, the first end of the first spiral trace **121** can be coupled to (e.g., form a continuous trace with) the ninth end of the fifth spiral trace within the first conductive layer. The first and second single-core, four-layer inductors **120** can therefore be fabricated in series to form a four-layer, dual-core inductor **120** with the eighth and sixteenth ends of the fourth and eighth spiral traces, respectively, forming the terminals of the four-layer, dual-core inductor **120**. Therefore, when these first and second multi-layer inductors **120** are driven to a first polarity, current can flow in a continuous circular direction through both the first multi-layer inductor

120 such that the first and second multi-layer inductors 120 produce magnetic fields in the same phase and in the same direction.

The controller 170 (or a driver): can be electrically connected to these terminals and can drive these terminals with an oscillating voltage during a haptic feedback cycle in order to induce: a first alternating magnetic field through the first single-core, four-layer inductor 120 (formed by the first, second, third, and fourth spiral traces 121, 122, 123, 124); and a second alternating magnetic field—in phase with the first alternating magnetic field—through the second single-core, four-layer inductor 120 (formed by the fifth, sixth, seventh, and eighth spiral traces). In particular, when the controller 170 drives the four-layer, dual-core inductor 120 at a first polarity, current can flow: in a continuous, clockwise direction through the first, second, third, and fourth spiral traces 121, 122, 123, 124 to induce a magnetic field in a first direction around the first single-core, four-layer inductor 120; and in a continuous, clockwise direction through the fifth, sixth, seventh, and eighth spiral traces to induce a magnetic field in the first direction around the second single-core, four-layer inductor 120. When the controller 170 reverses the polarity across terminals of the dual-core, four-layer inductor 120, current can reverse directions to: flow in a continuous, counter-clockwise direction through the first, second, third, and fourth spiral traces 121, 122, 123, 124 to induce a magnetic field in a second, opposite direction around the first single-core, four-layer inductor 120; and in a continuous, counter-clockwise direction through the fifth, sixth, seventh, and eighth spiral traces to induce a magnetic field in the second direction around the second single-core, four-layer inductor 120.

10.4 Double Core+Odd Quantity of Coil Layers

In a similar implementation, the substrate 110 includes an odd quantity of spiral traces fabricated within an odd quantity of layers within the substrate 110 to form a dual-core inductor 120.

For example, in this implementation, the dual-core inductor 120 can include two single-coil, three-layer inductors 120 connected in series. In this example, each single-coil, three-layer inductor 120 includes: an even number of single-coil layers; and an odd number of two-coil layers selectively connected to form a single-coil, three-layer inductor 120 that includes two terminals located on the periphery of the single-coil, three-layer inductor 120, as described above.

10.5 Horizontal Oscillation: Single-Core Multi-Layer Inductor

Generally, the keyboard system includes a set of magnetic elements 150, each: arranged within an individual key (or within a key location 132 of the tactile layer 130); and configured to magnetically couple to the corresponding multi-layer inductor 120 in the substrate 110 below during a haptic feedback cycle, thereby oscillating the individual key (or the key location 132 of the tactile layer 130) during a haptic feedback cycle.

In one implementation, each magnetic element 150 is arranged in a single key (or key location 132 in the tactile layer 130) relative to its corresponding multi-layer inductor 120 such that this multi-layer inductor 120 induces an oscillating force on the magnetic element 150 parallel to the substrate 110, thereby horizontally vibrating the corresponding individual key (or the individual key location 132 of the tactile layer 130) during a haptic feedback cycle, as shown in FIG. 9.

In this implementation, a key (or individual key location 132 within the tactile layer 130) can include a first magnet 151: embedded or overmolded within the key (or key location 132); defining a first magnetic polarity facing the corresponding multi-layer inductor 120 below; and extending along a first side of the primary axis of the multi-layer inductor 120. In this implementation, the key (or the individual key location 132 within the tactile layer 130) can similarly include a second magnet 152: embedded or overmolded within the key (or key location 132); defining a second (i.e., opposite) magnetic polarity facing the multi-layer inductor 120; and extending along a second side of the primary axis adjacent and opposite the first magnet 151.

In particular, the first magnet 151 can be arranged immediately adjacent the second magnet 152. The first and second magnets 151, 152 can be arranged directly over the multi-layer inductor 120 and can face the multi-layer inductor 120 with opposing polarities. When the controller 170 drives the multi-layer inductor 120 with an alternating voltage (or current), the multi-layer inductor 120 can generate a magnetic field that extends vertically through the substrate 110 and interacts with the opposing magnetic fields of the first and second magnets 151, 152. More specifically, when the controller 170 drives the multi-layer inductor 120 to a positive voltage during a haptic feedback cycle, the multi-layer inductor 120 can generate a magnetic field that extends vertically through the substrate 110 in a first vertical direction, which: attracts the first magnet 151 (arranged with the first polarity facing the multi-layer inductor 120); repels the second magnet 152 (arranged with the second polarity facing the multi-layer inductor 120); yields a first lateral force on the key in a first lateral direction; and shifts the key laterally in the first lateral direction relative to the substrate 110. When the controller 170 then reverses the voltage across the multi-layer inductor 120 during this haptic feedback cycle, the multi-layer inductor 120 can generate a magnetic field that extends vertically through the substrate 110 in the opposing vertical direction, which: repels the first magnet 151; attracts the second magnet 152; yields a second lateral force on the key in a second, opposite lateral direction; and shifts the key laterally in the second lateral direction relative to the substrate 110.

Therefore, by oscillating the polarity of the multi-layer inductor 120 at a key location 132, the controller 170 can: induce oscillating interactions (i.e., alternating attractive and repelling forces)—parallel to the substrate 110—between the multi-layer inductor 120 and the magnetic element 150 within the adjacent key; and thus oscillate the key (or the key location 132 of the tactile layer 130) horizontally over the substrate 110.

In this implementation, the spiral traces of a single-core multi-layer inductor 120 at a key location 132 can define: a first length (e.g., 0.4 inches) along the primary axis of the multi-layer inductor 120; and a first width (e.g., 0.25 inch, less than first length) along the secondary axis of the multi-layer inductor 120. Furthermore, the first magnet 151 located in the key above this multi-layer inductor 120 can define: a length parallel to and offset from the primary axis and approximating the first length of the spiral traces; and a second width parallel to the secondary axis of the multi-layer inductor 120 and approximately half of the first width of the spiral traces. The second magnet 152 located in the key above this multi-layer inductor 120 can similarly define: a length parallel to and offset from the primary axis and approximating the first length of the spiral traces; and a width parallel to the secondary axis of the multi-layer inductor 120 and approximately half of the first width of the spiral traces. The first and second magnets 151, 152 within this magnetic element 150 can be abutted and arranged on each side of the primary axis of the multi-layer inductor 120.

For example, this magnetic element **150** can include a permanent dipole magnet arranged in the corresponding key and centered over its corresponding multi-layer inductor **120** such that the two poles of the magnets within this magnetic element **150** are located on opposite sides of the primary axis of the multi-layer inductor **120**. As described above, this magnetic element **150** can also include a set of permanent dipole magnets arranged in an antipolar configuration (e.g., a Halbach array).

The controller **170** (or the driver) can therefore polarize a multi-layer inductor **120** under a key location **132** by applying an alternating voltage across the first and second terminals of the multi-layer inductor **120**, thereby inducing an alternating current through the set of spiral traces, inducing an alternating magnetic field normal to the touch sensor surface, inducing oscillating magnetic coupling between the multi-layer inductor **120** and the magnetic element **150** in the key (or tactile layer **130** above), and thus vibrating the key (or a location region of the tactile layer **130**) in a plane parallel to the substrate **110** during a haptic feedback cycle.

10.6 Horizontal Oscillation: Dual-Core Multi-Layer Inductor

Similarly, in the implementation described above in which the substrate **110** includes two adjacent single-core, multi-layer inductors **120** connected in series at each key location **132**, each key (or key location **132** within the tactile layer **130**) can include: a first magnet **151** defining a first magnetic polarity facing its corresponding first single-core multi-layer inductor **120** below and extending along a first side of a first primary axis of the first single-core multi-layer inductor **120**; a second magnet **152** defining a second magnetic polarity facing the first single-core multi-layer inductor **120** and extending along a second side of the first primary axis adjacent the first magnet **151**; a third magnet defining the second magnetic polarity facing the second single-core multi-layer inductor **120** and extending along a first side of a second primary axis of the second single-core multi-layer inductor **120**; and a fourth magnet defining the first magnetic polarity facing the second single-core multi-layer inductor **120** and extending along a second side of the second primary axis adjacent the third magnet.

Accordingly, by oscillating the polarity of the first and second single-core multi-layer inductors **120**—which include traces that spiral in the same direction and are therefore in-phase—the controller **170** can: induce oscillating interactions parallel to the substrate **110** between the first single-core multi-layer inductor **120**, the first magnet **151**, and the second magnet **152** and between the second single-core multi-layer inductor **120**, the third magnet, and the fourth magnet; and thus oscillate the key horizontally.

10.7 Vertical Oscillation

In another implementation, each key (or key location **132** within the tactile layer **130**) includes a magnetic element **150** arranged relative to its corresponding multi-layer inductor **120** such that the multi-layer inductor **120** at this key location **132** induces an oscillating force on the magnetic element **150** normal to the substrate **110** and therefore oscillates the key (or the key location **132** within the tactile layer **130**) vertically relative to the substrate **110** during a haptic feedback cycle, as shown in FIG. **10**.

In the implementation described above in which the substrate **110** includes a single-core multi-layer inductor **120**, each key can include a first magnet **151**: defining a first magnetic polarity facing the single-core multi-layer inductor **120**; approximately centered over the multi-layer inductor **120**; and extending laterally across the primary axis of the multi-layer inductor **120**. The first magnet **151** can thus generate a magnetic field that extends predominantly vertically toward the multi-layer inductor **120** and that is approximately centered over the multi-layer inductor **120**. More specifically, the first magnet **151** can generate a magnetic field that extends predominately normal to the substrate **110** proximal the center of the multi-layer inductor **120**. As shown in FIG. **10**, when the controller **170** drives the multi-layer inductor **120** to a positive voltage during a haptic feedback cycle, the multi-layer inductor **120** can generate a magnetic field that extends vertically through the substrate **110** in a first vertical direction, which: repels the first magnet **151** (arranged with the first polarity facing the multi-layer inductor **120**); yields a first vertical force in a first vertical direction on the first magnetic element **150**; and lifts the corresponding key (or key location **132** within the tactile layer **130**) vertically off of the substrate **110**. When the controller **170** then reverses the voltage across the multi-layer inductor **120** during this haptic feedback cycle, the multi-layer inductor **120** can generate a magnetic field that extends vertically through the substrate **110** in a second, opposite vertical direction, which: attracts the first magnet **151**; yields a second vertical force in a second, opposite vertical direction on the first magnet **151**; and draws the corresponding key (or key location **132** within eh tactile layer **130**) downward and back toward the substrate **110**.

Therefore, by oscillating the polarity of a multi-layer inductor **120** during a haptic feedback cycle, the controller **170** can: induce oscillating interactions (i.e., alternating attractive and repelling forces)—normal to the substrate **110**—between the multi-layer inductor **120** and the corresponding magnetic element **150**; and thus vertically oscillate the key (or key location **132** within the tactile layer **130**) containing the magnetic element **150**.

10.8 Vertical Oscillation: Dual-Core Multi-Layer Inductor

Similarly, in the implementation described above in which the substrate **110** includes two adjacent single-core, multi-layer inductors **120** connected in series and in phase (i.e., phased by 0°) at each key location **132**, each key can include a first magnet **151**: defining a first magnetic polarity facing the first single-core multi-layer inductor **120**; approximately centered over the first single-core multi-layer inductor **120**; and extending laterally across the primary axis of the first single-core multi-layer inductor **120**. The key can similarly include a second magnet **152**: defining the first magnetic polarity facing the second single-core multi-layer inductor **120**; approximately centered over the second single-core multi-layer inductor **120**; and extending laterally across the primary axis of the second single-core multi-layer inductor **120**.

Accordingly, by oscillating the polarity of the first and second single-core multi-layer inductors **120**—which are in-phase—at a key location **132**, the controller **170** can: induce oscillating interactions normal to the substrate **110** between the first single-core multi-layer inductor **120** and the first magnet **151** and between the second single-core multi-layer inductor **120** and the second magnet **152** at this key location **132**; and thus vertically oscillate the corresponding key (or this key location **132** in the tactile layer **130**).

11. Variation: Inverted Force Sensing

In one variation, the substrate **110** and force-sensitive layer **160** of the keyboard system **100** described above are inverted such that: the array of multi-layer inductors **120** are arranged across the upper layers of the substrate **110**; the set of keys are arranged over the top layer **115** of the substrate **110**; the array of drive electrode and sense electrode pairs **112** are arranged across the bottom layer(s) of the substrate

110; (an electrical shield (e.g., an actively-shielded ground electrode **119**) is integrated across a conductive layer of the substrate **110** between the array of multi-layer inductors **120** and the array of drive electrode and sense electrode pairs **112**); and the force-sensitive layer **160** is arranged across the bottom surface of the substrate **110** opposite the keys. In this variation, the keyboard system **100** can be arranged over a rigid planar surface within a chassis of a device, and the substrate **110** can communicate a force—applied to a particular key—downward to compress an adjacent region of the force-sensitive layer **160** between the substrate **110** and the chassis, thereby locally altering a bulk resistance of the force-sensitive layer **160** below this applied force, which the controller **170** can detect at a cluster of drive electrode and sense electrode pairs **112** and interpret as an input at a particular key arranged over this cluster of drive electrode and sense electrode pairs **112**.

12. Variation: Capacitive Sensing

In one variation shown in FIGS. **5** and **6**, the keyboard system **100** includes: a substrate **110**; a tactile layer **130**; an array of magnetic elements **150**; and a controller **170**. In this variation, the substrate **110** includes: an array of electrodes **112**; and an array of inductors **120** arranged below the array of electrodes **112**. The tactile layer **130**: is arranged over the substrate **110**; and defines an array of key locations **132** over the array of sense electrodes and the array of inductors **120**. Each magnetic element **150** in the array of magnetic elements **150** is: arranged within the tactile layer **130** at a key location **132** in the array of key locations **132**; and configured to inductively couple to an adjacent inductor **120** in the array of inductors **120**. The controller **170** is configured to read electrical values from the array of electrodes **112**. The controller **170** is further configured to, at a first time and in response to detecting a change in capacitance value at a first sense electrode, in the array of electrodes **112**: register a first keystroke of a first key type associated with a first key location **132**, in the array of key locations **132**, defined over the first sense electrode; and drive an oscillating voltage across a first inductor **120**, arranged below the first sense electrode, during a first haptic feedback cycle to a) induce alternating magnetic coupling between the first inductor **120** and a first magnetic element **150**, in the array of magnetic elements **150**, arranged within the tactile layer **130** below the first key location **132** and b) oscillate the tactile layer **130**, at the first key location **132**, relative to the substrate **110**.

12.1 Applications: Capacitive Sensing

In this variation, the substrate **110** can include an individual sense electrode (i.e., in a self-capacitance configuration) or a drive electrode and sense electrode pair **112** (i.e., in a mutual capacitance configuration) below each key location **132** of the tactile layer **130**. Depression of a key location **132** on the tactile layer **130** can thus move the adjacent magnetic element **150** downward toward the corresponding sense electrode on the substrate **110**, thereby effecting the capacitance of this sense electrode, which the controller **170** can read and interpret as a keystroke at this key location **132**. Additionally or alternatively, presence of a finger, stylus, or other object directly over this key location **132** may (further) effect the capacitance of this sense electrode. More specifically, the controller **170** can: read a capacitance value (e.g., charge time, discharge time, peak voltage, capacitance) from this sense electrode; detect depression or selection of this key location **132** if a difference between this capacitance value and a baseline capacitance value stored for the sense electrode exceeds a threshold difference; and thus register a keystroke of a key type associated with this key. Upon detecting depression of the key and registering this keystroke, the controller **170** can drive an oscillating voltage across the same inductor **120**, which generates an oscillating magnetic field that interacts with and oscillates the same magnetic element **150**—and therefore the key. The user may then perceive this oscillation of the key as downward movement of the key (e.g., analogous to a mechanical snapdome) or otherwise as haptic feedback indicating that the controller **170** registered a keystroke at the key.

Therefore, in this variation, a magnetic element **150** at a particular key location **132** can function to both: effect capacitance of an adjacent sense electrode on the substrate, which the controller **170** can interpret as a keystroke on the corresponding key; and to magnetically couple to the adjacent inductor **120** when the controller **170** drives the inductor **120** with an oscillating voltage, thereby vibrating the surface of the tactile layer **130** at this key location **132**.

12.2 Mutual Capacitance

In this variation, the substrate **110** can include: an array of electrodes **112**; and an array of inductors **120**, each paired with (e.g., arranged around or below) an electrode in the array.

In one implementation shown in FIGS. **5** and **6**, in a mutual-capacitance configuration, the keyboard system **100** includes: a drive electrode and sense electrode pair **112** arranged across the top layer **115** of the substrate at each key location **132**; trace connections between the drive electrode and sense electrode pairs **112** and the controller **170** across running across the first and/or second layers of the substrate; a ground electrode **119** arranged across a third layer **118** of the substrate; and a multi-layer inductor **120** spanning bottom layers of the substrate **110**—below the third layer **118**—below each key location **132**.

In this implementation, the tactile layer **130** can include an elastic sublayer **134** (e.g., a compressible silicone or urethane layer): interposed between the substrate **110** and the array of magnetic elements **150**; and configured to locally compress to enable movement of a first magnetic element **150** in a first key location **132** of the tactile layer **130** toward a first drive electrode and sense electrode pair **112**—on the top layer **115** of the substrate **110**—responsive to application of force over the first key location **132** on the tactile layer **130**, which effects (i.e., changes) capacitance between the first drive electrode and sense electrode pair **112**. The controller **170** can thus: read this change in capacitance from the first sense electrode; interpret this change in capacitance as a keystroke on the first key location **132** (e.g., if this capacitance differs from a stored baseline capacitance by more than a threshold difference); and drive an alternating voltage across the first multi-layer inductor **120**, which generates an oscillating magnetic field that a) extends through the upper layers of the substrate **110** and the elastic sublayer **134** and b) oscillates the first magnetic element **150** and the first key location **132** during a first haptic feedback cycle. Similarly, the elastic sublayer **134** of the tactile layer **130** can locally compress to enable movement of a second magnetic element **150** in a second key location **132** of the tactile layer **130** toward a second drive electrode and sense electrode pair **112**—on the top layer **115** of the substrate **110**—responsive to application of force over the second key location **132** on the tactile layer **130**, which effects capacitance between the second drive electrode and sense electrode pair **112**. The controller **170** can thus: read this change in capacitance from the second sense electrode; interpret this change in capacitance as a keystroke on the second key location **132**; and drive an alternating voltage across the second multi-layer inductor **120** in order to oscillate the second magnetic element **150** and the second key location **132** during a second haptic feedback cycle.

Alternatively, in this configuration, the keyboard system **100** can include: a multi-layer inductor **120** spanning the top and upper layers of the substrate **110** at each key location **132**; and a drive electrode and sense electrode pair **112** arranged across the top layer **115** of the substrate around (e.g., circumscribing) a multi-layer inductor **120** at each key location **132**. In this implementation, the first key location **132** of the tactile layer **130** can compress to enable the first magnetic element **150** to move toward the first multi-layer inductor **120** when the first key location **132** is depressed. The first magnetic element **150** can thus effect capacitance between the first drive electrode and sense electrode pair **112**, which the controller **170** can read from the first sense electrode and interpret as a keystroke at the first key location **132**. Accordingly, the controller **170** can drive an alternating voltage across the first multi-layer inductor **120** to oscillate the first magnetic element **150** and the first key location **132** during a haptic feedback cycle responsive to detecting this keystroke.

Additionally or alternatively, in this configuration, a finger in contact with a key location **132** on the tactile layer **130** can effect the capacitance of the drive electrode and sense electrode pair **112** under the corresponding key location **132**, and the controller **170** can interpret a keystroke at this key location **132** and execute a haptic feedback cycle at this multi-layer inductor **120** accordingly.

However, in this variation, the set of keys and/or the tactile layer **130** can define any other form of discrete or continuous keys, such as described above, and the controller **170** can implement similar methods and techniques to detect keystrokes at these key locations **132**.

12.3 Self Capacitance

Alternatively, in a self-capacitance configuration, the keyboard system **100** includes: a sense electrode arranged on the top layer **115** of the substrate at each key location **132**; a ground electrode **119** arranged across a second layer **117** of the substrate; and a multi-layer inductor **120** spanning bottom layers of the substrate **110**—below the second layer **117**—below each key location **132**.

In a similar implementation, the keyboard system **100** includes: a multi-layer inductor **120** spanning the top and upper layers of the substrate **110** below each key location **132**; and a sense electrode arranged on the top layer **115** of the substrate around a multi-layer inductor **120** at each key location **132**. Thus, in this implementation, a sense electrode can be particularly sensitive to detecting a finger on the key location **132** of the tactile layer **130** overhead the sense electrode, and the multi-layer inductor **120** adjacent this sense electrode can be nearest to and exhibit greatest capacitive coupling to the magnetic element **150** at this location.

In a similar implementation, the keyboard system **100** includes: a multi-layer inductor **120** spanning the top and upper layers of the substrate **110** below each key location **132**; and a sense electrode arranged on the top layer **115** of the substrate and located proximal the center of a multi-layer inductor **120** at each key location **132**. Thus, in this implementation, a sense electrode can be particularly sensitive to detecting motion of the magnetic element **150** toward the substrate when the tactile layer **130** overhead the sense electrode is depressed.

In this configuration, a sense electrode at a key location **132** can capacitively couple to the magnetic element **150** above. Therefore, depression of the tactile layer **130** at this key location **132** can move this magnetic element **150** toward the multi-layer inductor **120**, thereby effecting the capacitance of this sense electrode. The controller **170** can interpret the resulting change in capacitance of the sense electrode as a keystroke at this key location **132** and execute a haptic feedback cycle at this multi-layer inductor **120** accordingly.

Additionally or alternatively, a sense electrode at a key location **132** can capacitively couple to a finger in contact with or depressing the corresponding key location **132** on the tactile surface above. Therefore, presence of a finger on the tactile layer **130** at this key location **132** depression can effect the capacitance of this sense electrode. The controller **170** can interpret the resulting change in capacitance of the sense electrode as a keystroke at this key location **132** and execute a haptic feedback cycle at this multi-layer inductor **120** accordingly.

Alternatively, magnetic elements in the key elements can be connected to a reference potential or to ground. Accordingly, a sense electrode at a key location **132** can capacitively couple to the magnetic element in the key element above. Therefore, depression of the key element (e.g., by a finger on the tactile layer **130** at this key location **132**) can move the magnetic element toward the sense electrode effect the capacitance of this sense electrode. The controller **170** can interpret the resulting change in capacitance of the sense electrode as a keystroke at this key location **132** and execute a haptic feedback cycle at this multi-layer inductor **120** accordingly.

Yet alternatively, the system **100** can include a conductive film or layer arranged above or below these magnetic elements, arranged above the array of sense electrodes, and connected to a reference potential or to ground. Accordingly, a sense electrode at a key location **132** can capacitively couple to this conductive film. Therefore, depression of the key element (e.g., by a finger on the tactile layer **130** at this key location **132**) can locally move the conductive film toward the sense electrode and effect the capacitance of this sense electrode. The controller **170** can interpret the resulting change in capacitance of the sense electrode as a keystroke at this key location **132** and execute a haptic feedback cycle at this multi-layer inductor **120** accordingly.

However, in this variation, the keyboard system can include an array of electrodes **112** arranged in any other configuration.

12.4 Controller

Therefore, in this variation, the controller **170** can: read electrical values in the form of capacitance values from the array of electrodes **112**; and register a first keystroke of a first key type in response to a capacitance value—read from a first sense electrode under a first key location **132** on the tactile layer **130**—differing from a stored baseline capacitance value for the first sense electrode by more than a first threshold capacitance value, the first threshold capacitance value corresponding to a minimum keystroke force.

In one implementation described above, a first magnetic element **150** at a first key location **132** in the tactile layer **130** affects capacitance of a first sense electrode in the substrate **110** responsive to movement of the first magnetic element **150** toward a first multi-layer inductor **120** under this first key location **132**. Similarly, a second magnetic element **150** at a second key location **132** in the tactile layer **130** affects capacitance of a second electrode in the substrate **110** responsive to movement of the second magnetic element **150** toward a second multi-layer inductor **120** under this second key location **132**.

Accordingly, in response to detecting a first change in electrical value (e.g., in a first direction, such as increase in charge time, decrease in peak voltage, increase in capacitance, decrease in circuit frequency) at a first sense electrode at a first key location **132**, the controller **170** can: register a first keystroke of a first key type associated with the first key location **132**; and drive an oscillating voltage across a first inductor **120** under the first key location **132** during a first haptic feedback cycle to a) induce alternating magnetic coupling between the first inductor **120** and a first magnetic element **150** arranged within the tactile layer **130** at the first key location **132** and b) oscillate the tactile layer **130**, at the first key location **132**, relative to the substrate **110**, thereby communicating haptic feedback into a user's finger or stylus to indicate that the controller **170** registered the first keystroke. However, because the tactile layer **130** (e.g., the elastic sublayer **134**) is elastic, the tactile layer **130** can return the first magnetic element **150** back to its nominal condition as the force on the first key location **132** is removed, thereby returning the capacitance of the first sense electrode to (or near) its baseline capacitance. Therefore, in response to detecting a second change in electrical value (e.g., in a second direction, such as decrease in charge time, increase in peak voltage, decrease in capacitance, increase in circuit frequency) at the first sense electrode, the controller **170** can: register release of the first key location **132**; and drive an oscillating voltage (e.g., at a higher frequency, over a shorter duration, and/or at a lower amplitude) across the first inductor **120** during a second haptic feedback cycle to a) induce alternating magnetic coupling between the first inductor **120** and the first magnetic element **150** and b) oscillate the tactile layer **130**, at the first key location **132**, relative to the substrate **110**, thereby communicating haptic feedback into the user's finger or stylus to indicate that the controller **170** detected release of the first key location **132**.

Similarly, in response to detecting a third change in electrical value (e.g., in the first direction) at the second inductor **120**, the controller **170** can: register a second keystroke of a second key type associated with the second key location **132** defined over the second multi-layer inductor **120**; and drive the oscillating voltage across the second inductor **120** during a third haptic feedback cycle to a) induce alternating magnetic coupling between the second inductor **120** and the second magnetic element **150** arranged within the tactile layer **130** at the second key location **132** and b) oscillate the tactile layer **130**, at the second key location **132**, relative to the substrate **110**. Furthermore, in response to detecting a fourth change in electrical value (e.g., in the second direction) at the first sense electrode, the controller **170** can: register release of the second key location **132**; and drive an oscillating voltage (e.g., at the higher frequency, over the shorter duration, and/or at the lower amplitude) across the second inductor **120** during a fourth haptic feedback cycle to a) induce alternating magnetic coupling between the second inductor **120** and the second magnetic element **150** and b) oscillate the tactile layer **130**, at the second key location **132**, relative to the substrate **110**, thereby communicating haptic feedback into the user's finger or stylus to indicate that the controller **170** detected release of the second key location **132**.

13. Variation: Inductive Sensing

In one variation shown in FIGS. **7-10**, the keyboard system **100** includes: a substrate **110**; a tactile layer **130**; an array of magnetic elements **150**; and a controller **170**. The substrate **110** includes an array of inductors **120**. The tactile layer **130**: is arranged over the substrate **110**; and defines an array of key locations **132** over the array of inductors **120**. Each magnetic element **150** in the array of magnetic elements **150**: is arranged within the tactile layer **130** at a key location **132** in the array of key locations **132**; is configured to inductively couple to an adjacent inductor **120** in the array of inductors **120**; and is configured to move relative to the adjacent inductor **120** responsive to application of a force on the tactile layer **130** at the key location **132**. The controller **170** is configured to read electrical values from the array of inductors **120**. The controller **170** is further configured to, at a first time and in response to detecting a first change in electrical value at a first inductor **120**, in the array of inductors **120**: register a first keystroke of a first key type associated with a first key location **132**, in the array of key locations **132**, defined over the first inductor **120**; and drive an oscillating voltage across the first inductor **120** during a first haptic feedback cycle to a) induce alternating magnetic coupling between the first inductor **120** and a first magnetic element **150**, in the array of magnetic elements **150**, arranged within the tactile layer **130** at the first key location **132** and b) oscillate the tactile layer **130**, at the first key location **132**, relative to the substrate **110**.

In this variation, the controller **170** can further, at a second time and in response to detecting a second change in electrical value at a second inductor **120**, in the array of inductors **120**: register a second keystroke of a second key type associated with a second key location **132** defined over the second inductor **120**; and drive the oscillating voltage across the second inductor **120** during a second haptic feedback cycle to a) induce alternating magnetic coupling between the second inductor **120** and the second magnetic element **150** arranged within the tactile layer **130** at the second key location **132** and b) oscillate the tactile layer **130**, at the second key location **132**, relative to the substrate **110**.

13.1 Applications: Inductive Sensing

Generally, in this variation, rather than detect depression of a key based on a change in resistance or capacitance across electrodes at key locations **132** on the substrate **110**, magnetic elements **150** in the keys can inductively (or "magnetically") couple to their adjacent inductors **120**. When a user depresses an individual key in the keyboard, the magnetic element **150** within the key moves toward its corresponding inductor **120**, thereby changing a magnetic field and magnetic flux through the inductor **120**, inducing a voltage in a first direction across the inductor **120**, and/or causing current to flow in a first direction through the inductor **120**. In this variation, the controller **170** can read a magnitude of this voltage and/or current moving through the inductor **120**. The controller **170** can thus detect depression of the key and register a keystroke of the corresponding key type: if the magnitude of this voltage exceeds a threshold voltage; if the integral of the magnitude of this voltage over a time interval (e.g., 50 milliseconds) exceeds a threshold keystroke value; or if the current moving through the inductor **120** within a time interval exceeds a threshold current—which may indicate depression of the key with sufficient force over a limited time interval characteristic of depression of a mechanical switch, button, or snapdome. Upon detecting depression of the key and registering a keystroke of the corresponding key type, the controller **170** can drive an oscillating voltage across the same inductor **120**, which generates an oscillating magnetic field that interacts with and oscillates the same magnetic element **150**—and therefore the key. The user may then perceive this oscillation of the key as downward movement of the key (e.g., analogous to a mechanical snapdome) or otherwise as haptic feedback indicating that the controller **170** registered a keystroke at the key.

Therefore, in this variation, the keyboard system **100** can omit sense electrodes and/or drive electrode at each key location **132** and/or a force-sensitive layer **160**, as described above. Rather, the keyboard system **100** can include a single inductor **120** and magnetic element **150** pair at each key location **132**. The controller **170** can both: detect an input on an individual key of the keyboard based on changes in voltage across or current through the inductor **120** below this individual key; and return haptic feedback at the individual key by driving an oscillating voltage across this particular inductor **120**. More specifically, in this variation, the single inductor **120** and the single magnetic element **150** located at each key location **132** can function both: as a sensor configured to detect inputs on the corresponding key; and as a haptic actuator configured to return vibratory feedback to a finger or other object depressing the key.

13.2 Tactile Layer

Generally, the tactile layer **130** is arranged over the substrate **110** and defines an array of key locations **132** over the array of inductors **120** integrated into the substrate **110**.

13.2.1 Contiguous Elastic Layer with Embedded Magnetic Elements

In one implementation described above and shown in FIGS. **7** and **8**, the tactile layer **130** includes an elastic sublayer **134** that defines a unitary structure and forms a contiguous surface spanning the array of key locations **132**. In this implementation, each magnetic element **150**—in the array of magnetic elements **150** integrated into the tactile layer **130**—can include a single magnet or a magnetic array (e.g., a Halbach array) embedded or overmolded in the elastic sublayer **134** below a key location **132** in the array of key locations **132** defined across the tactile layer **130**.

For example, the tactile layer **130** can be assembled by: injection molding or casting a bottom silicone or urethane layer that includes a shallow recess or counterbore at each key location **132**; locating a preformed magnetic element **150** in each recess or counterbore on the first layer **116**; molding a top silicone or urethane layer defining concave or convex ridges around each key location **132**; and the bonding or vulcanizing a top layer **115** onto the bottom layer to enclose the magnetic elements **150**.

In another example, the tactile layer **130** can be assembled by: locating magnetic elements **150** at key locations **132** within a mold; and then shooting a polymer (e.g., silicone, urethane) into the mold to encapsulate the magnetic elements **150** and complete the tactile layer **130**.

Therefore, in this implementation, application of a force on the tactile layer **130** at a key location **132** can compress a region of the elastic sublayer **134** below this force and thus move a magnetic element **150** at this key location **132** toward the multi-layer inductor **120** such that the magnetic element **150** induces current flow through a multi-layer inductor **120** below the magnetic element **150**. The controller **170** can detect this current flow through this multi-layer inductor **120** as a keystroke at this key location **132**.

13.2.2 Contiguous Elastic Sublayer Below Key Elements

In another implementation shown in FIGS. **5** and **6**, the tactile layer **130** includes: an elastic sublayer **134** arranged over the substrate **110**; a set of discrete rigid key elements **140** arranged over and coupled (e.g., bonded) to the elastic sublayer **134** at key locations **132**; and a set of magnetic elements **150** integrated into discrete keys or into the elastic sublayer **134** at the key locations **132**.

For example, in this implementation, each discrete rigid key element **140** can: be coupled to a discrete region of the elastic sublayer **134** over a multi-layer inductor **120** integrated into the substrate **110**; define a key location **132**; and house a magnetic element **150**. In this example, responsive to application of a force on the discrete rigid key element **140**, the discrete rigid key can compress this discrete region of the elastic sublayer **134** and thus move the magnetic element **150** toward the multi-layer inductor **120** such that the magnetic element **150** induces current flow through the multi-layer inductor **120** under this key location **132**. The controller **170** can detect this current flow through this multi-layer inductor **120** as a keystroke at this key location **132**.

In particular, in this variation, the tactile layer **130** can include an elastic sublayer **134** (or layer, material): interposed between the substrate **110** and the array of magnetic elements **150**; configured to locally compress to enable movement of a first magnetic element **150** toward a first inductor **120** responsive to application of force over a first key location **132** on the tactile layer **130**; configured to locally compress to enable movement of a second magnetic element **150** toward a second inductor **120** responsive to application of force over a second key location **132** on the tactile layer **130**; etc. The first magnetic element **150** inductively couples to the first inductor **120** and induces current flow in a first direction through the first inductor **120** as the first magnetic element **150** moves downward from its nominal position toward the first inductor **120** during depression of the first key location **132**. However, the elastic sublayer **134** is configured to elastically deform and to return the first magnetic element **150** to its nominal position when a force on the first key location **132** of the tactile layer **130** is released. Accordingly, the first magnetic element **150** can induce current flow in a second, opposite direction through the first inductor **120** as the first magnetic element **150** moves away from the first inductor **120** and back toward its nominal position when a force on the first key location **132** is released.

Similarly, the second magnetic element **150** inductively couples to the second inductor **120** and induces current flow in the first direction through the second inductor **120** as the second magnetic element **150** moves downward from its nominal position toward the second inductor **120** during depression of the second key location **132**. The second magnetic element **150** also induces current flow in the second, opposite direction through the second inductor **120** as the second magnetic element **150** moves away from the second inductor **120** and back toward its nominal position when a force on the second key location **132** is released.

13.2.3 Discrete Keys with Retention Posts

In another implementation shown in FIGS. **1** and **2**, the keyboard system **100** includes multiple discrete keys that cooperate to form the tactile layer **130**, wherein each discrete key defines a retention post **142** installed through a bore at a corresponding key location **132** in the substrate **110**.

For example, in this implementation, the substrate **110** can define an array of bores adjacent the array of inductors **120**, such as centered inside and passing through the cores of these inductors **120**. In this example, the keyboard system **100** can include a set of discrete key elements **140** arranged over the substrate and cooperating to form the tactile layer **130**. Each discrete key element **140**: defines a key face; includes an elastic post extending rearward from the key face; is installed over an inductor **120** with its elastic post a) extending through a bore in the substrate **110** and b) retaining the discrete key element **140** over the substrate **110**; and houses a magnetic element **150**.

Furthermore, responsive to application of a force on its key face, a discrete key element **140** can compress against the substrate and move the magnetic element **150**—located within the discrete key element **140**—toward the adjacent inductor **120** at this key location **132** such that the magnetic element **150** induces current flow through the inductor **120** in a first direction. The controller **170** can: detect this current flow through this inductor **120** in the first direction (or detect a voltage across the inductor **120** at a first polarity) as a keystroke at this key location **132**; and execute a haptic feedback cycle (e.g., a "keystroke" haptic feedback cycle) at this inductor **120** to tactilely indicate detection of a keystroke at this key location **132**.

Similarly, responsive to release of the force from the key face, this discrete key element **140** can rebound (or "spring back") to move the magnetic element **150** away from the adjacent inductor **120** and back toward its nominal position over the inductor **120** such that the magnetic element **150** induces current flow through the inductor **120** in a second, opposite direction. The controller **170** can: detect this current flow through this inductor **120** in the second direction (or detect a voltage across the inductor **120** at a second, opposite polarity) as release of this key location **132**; and execute a haptic feedback cycle (e.g., a "release" haptic feedback cycle at a higher frequency, at a lower amplitude, and/or over a shorter duration) at this inductor **120** to tactilely indicate detection of release of this key location **132** and completion of the keystroke.

13.3 Substrate and Inductors: In-Plane/Horizontal Oscillation

As described above, the substrate **110** can define a unitary structure including: a first layer **116** that includes a first array of spiral traces; and a second layer **117** arranged below the first layer **116** opposite the tactile layer **130** and that includes a second array of spiral traces. Each spiral trace in the first layer **116** can be located below a key location **132** on the tactile layer **130**, can be coiled in a first direction, and can define a first end and a second end. Each spiral trace in the second layer **117**: can be located below a key location **132** in the array of key locations **132**; can be coiled in a second direction opposite the first direction; can define a third end and a fourth end, the third end electrically coupled to a second end of a first spiral trace in the first array of spiral traces; and can cooperate with the adjacent spiral trace to form a first loop—of an inductor **120** arranged below a key location **132**—that defines a primary axis.

In this implementation and as described above, a first magnetic element **150** located at a first key location **132** in the tactile layer **130** includes: a first magnet **151** arranged over the first inductor **120** on a first side of a primary axis of the first inductor **120** and defining a first polarity facing the first inductor **120**; and a second magnet **152** adjacent the first magnet **151**, arranged over the first inductor **120** on a second side of a primary axis of the first inductor **120** opposite the first magnet **151**, and defining the first polarity facing away from the first inductor **120**.

Then, in response to detecting a keystroke at the first key location **132** on the tactile layer **130**, the controller **170** can drive an oscillating voltage across the first inductor **120** during a haptic feedback cycle to: induce alternating magnetic coupling between the first inductor **120**, the first magnet **151**, and the second magnet **152**; and oscillate the tactile layer **130**—at the first key location **132** containing the first and second magnets **151**, **152**—parallel to the substrate **110** (i.e., horizontally), as shown in FIG. **9**.

13.4 Normal/Vertical Oscillation

In another implement described above, the substrate **110** can define a unitary structure including: a first layer **116** that includes a first array of spiral traces and a third array of spiral traces; and a second layer **117** arranged below the first layer **116** opposite the tactile layer **130** and that includes a second array of spiral traces and a fourth array of spiral traces. Each spiral trace in the first array of spiral traces in the first layer **116** can be located below a key location **132** on the tactile layer **130**, can be coiled in a first direction, and can define a first end and a second end. Each spiral trace in the second array of spiral traces in the second layer **117**: can be located below a key location **132** in the array of key locations **132**; can be coiled in a second direction opposite the first direction; can define a third end and a fourth end, the third end electrically coupled to a second end of a first spiral trace in the first array of spiral traces; and can cooperate with the adjacent spiral trace to form a first loop—of an inductor **120** arranged below a key location **132**—that defines a primary axis. Each spiral trace in the third array of spiral traces in the first layer **116**: can be adjacent a first spiral trace in the first array of spiral traces; can be coiled in the second direction; and can define a fifth end and a sixth end, the fifth end electrically coupled to the first end of the first spiral trace.

Similarly, in this implementation, each spiral trace in the fourth array of spiral traces in the second layer **117**: can be adjacent a second spiral trace in the second array of spiral traces; can be coiled in the first direction; can define a seventh end and an eighth end, the seventh end electrically coupled to a sixth end of a third spiral trace in the third array of spiral traces; can cooperate with a first spiral trace in the first array of spiral traces, the second spiral trace, and the third spiral trace to form an inductor **120** below a key location **132** on the tactile layer **130**; and can cooperate with the third spiral trace to form a second loop of the inductor **120** such that the second loop of the inductor **120** defines a secondary axis parallel to and offset from a primary axis of a first loop of the inductor **120**.

Furthermore, in this implementation, a first magnetic element **150** at a first key location **132** can include: a first magnet **151** arranged over a primary axis of a first loop of the first inductor **120** and defining a first polarity facing a first inductor **120** in the substrate **110**; and a second magnet **152** adjacent the first magnet **151**, arranged over a secondary axis of a second loop of the first inductor **120**, and defining the first polarity facing away from the first inductor **120**.

Then, in response to detecting a keystroke at the first key location **132** on the tactile layer **130**, the controller **170** can drive a oscillating voltage across the first inductor **120** during the first haptic feedback cycle to: induce alternating magnetic coupling between the first magnet **151** and the first loop of the first inductor **120**; induce alternating magnetic coupling between the second magnet **152** and the second loop of the first inductor **120**; and oscillate the tactile layer **130**—at the first key location **132**—normal to the substrate **110** (i.e., vertically), as shown in FIG. **10**.

13.5 Controller

Generally, the controller **170** is configured to: read electrical values (e.g., current directions and amplitudes; voltage polarities and amplitudes) from the array of inductors **120**; register keystrokes at particular key locations **132** on the tactile layer **130** responsive to changes in electrical values at inductors **120** (e.g., from baseline "null" current amplitudes) under these key locations **132**; and to drive oscillating voltages across these inductors **120** during haptic feedback cycles responsive to detecting keystrokes at these key locations **132**.

13.5.1 Keystroke Detection

In this variation, the tactile layer **130** can include an elastic sublayer **134** (or layer, material): interposed between the substrate **110** and the array of magnetic elements **150**; configured to locally compress to enable movement of each magnetic elements **150** at a key location **132** toward its corresponding inductor **120** responsive to application of a force over this key location **132** on the tactile layer **130**; and configured to rebound (or "spring back") to return each magnetic element **150** to its nominal position over its corresponding inductor **120** when a force is released from this key location **132** on the tactile layer **130**. Movement of a magnetic element **150** toward its corresponding inductor **120**—when a force is applied to the tactile layer **130** at the corresponding key location **132** (e.g., with a finger or stylus)—induces inductive coupling between the magnetic element **150** and the inductor **120** and causes current to flow in a first direction through the inductor **120** and thus generates a voltage of a first polarity across the inductor **120**.

As shown in FIGS. **9** and **10**, the controller **170** can: detect this current flow and direction through the inductor **120** (e.g., via an ammeter connected to the controller **170** and/or detect this voltage and voltage polarity across the inductor **120** (e.g., via an integrated or connected analog-to-digital converter) when the corresponding key location **132** is depressed; and register a keystroke—of a key type associated with this key location **132** and inductor **120**—such as if the total current through the inductor **120**, the total current through the inductor **120** within a threshold time interval (e.g., 1 millisecond), the peak voltage across the inductor **120**, or the integral of voltages across the inductor **120** over the time interval aligns with a first current direction or first voltage polarity and exceeds a threshold keystroke value. Upon registering this keystroke at this key location **132**, the controller **170** can: output a key type associated with this key location **132** (e.g., to a connected device or processor); set an "active keystroke" flag for this key location **132**; and output an oscillating voltage to the inductor **120**, which inductively couples to the adjacent magnetic element **150** and vibrates the tactile layer **130** at this key location **132**, as described above.

13.5.2 Release Detection

As described above and shown in FIG. **9**, the tactile layer **130** is configured to elastically deform and to return magnetic elements **150** to their nominal position when force on the tactile layer **130** at corresponding key locations **132** are released. Accordingly, each magnetic element **150** can induce current flow in a second, opposite direction through an adjacent inductor **120** as the tactile layer **130** moves the magnetic element **150** away from this inductor **120** and back toward its nominal position when a force on the corresponding key location **132** is released.

For example, the tactile layer **130** can include an elastic sublayer **134** (or layer, material): interposed between the substrate **110** and the array of magnetic elements **150**; configured to locally compress to enable movement of a magnetic element **150**—at a key location **132** on the tactile layer **130**—toward its corresponding inductor **120** responsive to application of a force over this key location **132**; and configured to rebound (or "spring back") to return each magnetic element **150** to its nominal position over its corresponding inductor **120** when a force is released from this key location **132** on the tactile layer **130**. Movement of a magnetic element **150** away from its corresponding inductor **120**—when a force previously applied to the tactile layer **130** at the corresponding key location **132** (e.g., with a finger or stylus) is released—induces inductive coupling between the magnetic element **150** and the inductor **120** and causes current to flow in a second, opposite direction through the inductor **120** and thus generates a voltage of a second polarity across the inductor **120**.

The controller **170** can: detect this current flow and direction through the inductor **120** and/or detect this voltage and voltage polarity across the inductor **120** when the corresponding key location **132** is released; and then register a key release event and/or completion of a keystroke, such as if the total current through the inductor **120**, the total current through the inductor **120** within a threshold time interval (e.g., 1 millisecond), the peak voltage across the inductor **120**, or the integral of voltages across the inductor **120** over the time interval aligns with a second current direction or second voltage polarity and exceeds a threshold key release value (e.g., less than the threshold keystroke value described above). Upon registering this keystroke release at this key location **132**, the controller **170** can: clear an active keystroke flag for this key location **132**; and output an oscillating voltage to the inductor **120** (e.g., at a higher frequency, over a shorter duration, and/or at a lower amplitude than a keystroke haptic feedback cycle when a keystroke at this key location **132** was last detected), which inductively couples to the adjacent magnetic element **150** and vibrates the tactile layer **130** at this key location **132**, as described above, to tactilely indicate to a user that the controller **170** detected and registered release of this key location **132**.

13.5.3 Examples

For example, in this variation, the controller **170** can: read electrical values from the array of inductors **120** by tracking voltage across the array of inductors **120**; detect a first voltage of a first polarity across a first inductor **120** at a first time (e.g., during a first scan cycle); register a first keystroke of a first key type associated with the first inductor **120** in response to detecting the first voltage of the first polarity across the first inductor **120**; and drive an oscillating voltage across the first inductor **120** during a first haptic feedback cycle in response to registering the first keystroke. Later, the controller **170** can: detect a second voltage of a second polarity—opposite the first polarity—across the first inductor **120** at a second time succeeding the first time (e.g., during a second scan cycle succeeding the first scan cycle); register release of the first keystroke from the first key location **132** on the tactile layer **130** in response to detecting the second voltage at the second polarity across the first inductor **120**; and drive a second oscillating voltage across the first inductor **120** during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location **132**.

Furthermore, in this example, the controller **170** can: register the first keystroke of the first key type in response to the first voltage exceeding a first threshold voltage magnitude; drive the oscillating voltage across the first inductor **120** at a first frequency during the first haptic feedback cycle in response to registering the first keystroke; register release of the first keystroke from the first key location **132** on the tactile layer **130** in response to the second voltage exceeding a second threshold voltage magnitude less than the first threshold voltage magnitude; and drive the second oscillating voltage across the first inductor **120** at a second frequency greater than the first frequency during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location **132**.

In another example, the controller **170** can: read electrical values from the array of inductors **120** by tracking current flow through the array of inductors **120**; detect a first change in electrical value including a first current moving through the first inductor **120** in a first direction at a first time (e.g., during a first scan cycle); register the first keystroke of the first key type in response to detecting the first current moving through the first inductor **120** in the first direction; and drive the oscillating voltage across the first inductor **120** during a first haptic feedback cycle in response to registering the first keystroke. Later, the controller **170** can: detect a second current moving through the first inductor **120** in a second direction opposite the first direction at a second time succeeding the first time (e.g., during a second scan cycle); register release of the first keystroke from the first key location **132** on the tactile layer **130** in response to detecting the second current moving through the first inductor **120** in the second direction; and drive a second oscillating voltage across the first inductor **120** during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location **132**.

In this example, the controller **170** can also: register the first keystroke of the first key type in response to the first current, moving through the first inductor **120** in the first direction, exceeding a first threshold current amplitude; drive the oscillating voltage across the first inductor **120** at a first frequency during the first haptic feedback cycle in response to registering the first keystroke; register release of the first keystroke from the first key location **132** on the tactile layer **130** in response to the second current, moving through the first inductor **120** in the second direction, exceeding a second threshold current amplitude less than the first threshold current amplitude; and drive the second oscillating voltage across the first inductor **120** at a second frequency greater than the first frequency during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location **132**.

13.5.4 Inductor Sampling

In one implementation shown in FIG. **11**, the array of inductors **120** is connected to a set of row and column traces, and the controller **170** can be coupled to the array of inductors **120** via a coil driver **171** and these row and column traces. Accordingly, the controller **170** can selectively execute a haptic feedback cycles at a particular inductor **120** by triggering the coil driver **171** to drive oscillating voltages across a particular combination of one row trace and one column trace uniquely connected to this particular inductor **120**. In this implementation, the controller **170** (or other reader connected to these row and column traces) can also serially read currents through and/or voltages across individual inductors **120** during a scan cycle and detect keystrokes and key releases from individual key locations **132** on the tactile layer **130** during this scan cycle based on these currents and/or voltages. For example, during a scan cycle, the controller **170** can: read a first voltage across a first row trace and a first column trace corresponding to a first inductor **120** in the substrate **110**; read a second voltage across the first row trace and a second column trace corresponding to a second inductor **120** in the substrate **110**; read a third voltage across the first row trace and a third column trace corresponding to a third inductor **120** in the substrate **110**; and repeat this process for each other row and column trace combination to read voltages at each inductor **120** during this scan cycle.

The controller **170** can then: detect selection of the first key location **132** on the tactile layer **130** during this scan cycle if the first voltage exhibits a first polarity (e.g., is positive) and is greater than a threshold voltage; register a new keystroke at the first key location **132** and set an "active keystroke" flag for the first key location **132** if an active keystroke flag is not currently set for the first key location **132**; and trigger the coil driver **171** to execute a keystroke haptic feedback cycle at the first inductor **120**. Similarly, the controller **170** can: detect selection of the second key location **132** on the tactile layer **130** during this scan cycle if the second voltage exhibits the first polarity and is greater than the threshold voltage; but discard this selection at the second key location **132** if an active keystroke flag is currently set for the second key location **132**. (The controller **170** can also clear the active keystroke flag for the second key location **132** after a threshold duration of time (e.g., 700 milliseconds) after this active keystroke flag was last set for the second key location **132**.) Additionally or alternatively, the controller **170** can: detect release of the third key location **132** on the tactile layer **130** during this scan cycle if the second voltage exhibits a second, opposite polarity and is greater than the threshold voltage; clear the "active keystroke" flag for the third key location **132** if an active keystroke flag is currently set for the third key location **132**; and trigger the coil driver **171** to execute a release haptic feedback cycle at the third inductor **120**. The controller **170** can repeat this process for each other key location **132** and voltage read during this scan cycle.

The controller **170** can then repeat this process for each subsequent scan cycle, such as at a rate of 20 Hz.

Furthermore, in the foregoing implementation, while executing a haptic feedback cycle (e.g., a keystroke or release haptic feedback cycle) at a particular inductor **120**, the controller **170** can selectively sample only row and column traces not connected to the particular inductor **120**. In particular, because the particular inductor **120** may induce high-amplitude noise through the row and column traces connected thereto during a haptic feedback cycle, the controller **170** can selectively sample only row and column traces not connected to the particular inductor **120** during subsequent scan cycles until the coil driver **171** completes the haptic feedback cycle at the particular inductor **120**, at which time the controller **170** can resume scanning the row and column traces connected to the particular inductor **120**.

Conversely, the controller **170** (or other reader) and the coil driver **171** can be directly and selectively coupled to each inductor **120**, such as via a multiplexer and a demultiplexer, respectively. For example, the coil driver **171** can selectively execute a haptic feedback cycle at a particular inductor **120** by selectively addressing the particular inductor **120** via a demultiplexer. As the coil driver **171** executes this haptic feedback cycle at the particular inductor **120**, the controller **170** can: serially select and then read voltages across or currents through each other inductor **120** in the keyboard system **100**; interpret keystrokes and/or keystroke releases on key locations **132** over these other inductors **120**; and selectively trigger the coil driver **171** to execute subsequent haptic feedback cycles at these other inductors **120** accordingly. Once the coil driver **171** completes the haptic feedback cycle at the particular inductor **120**, the controller **170** can resume reading read voltages across or currents through the particular inductor **120** and each other inductor **120** in the keyboard system **100** not currently undergoing a haptic feedback cycle.

13.6 Illumination

As described above, in this variation, the keyboard system **100** can further include a set of light elements **180** configured to illuminate (or "backlight") key locations **132** across the tactile layer **130** or discrete key elements **140**.

In one example shown in FIGS. **5** and **6**, the tactile layer **130** includes an array of translucent regions **144** arranged within the array of key locations **132**, such as translucent elastomeric or rigid elements in the form of alphanumeric and keyboard characters cast or molded into the tactile layer **130** at each key location **132** and extending through the thickness of the tactile layer **130**. In this example, each inductor **120** can define a spiral trace: fabricated on a first layer **116** of the substrate **110** facing the tactile layer **130**; and facing a key location **132** of the tactile layer **130**. The keyboard system **100** further includes an array of light elements **180**. Each light element **180**: is arranged on the top layer **115** of the substrate **110** adjacent (e.g., centered within or located adjacent a perimeter of) a spiral trace of an inductor **120** at a key location **132**; faces the tactile layer **130**; and is configured to illuminate a translucent region **144** within the adjacent key location **132** of the tactile layer **130**. In this example, the back layer of the tactile layer **130** can include recesses to accommodate these light elements **180**, and the translucent elements within the tactile layer **130** can be arranged directly over these light elements **180**.

As shown in FIG. **9**, the tactile layer **130** can include a network of light pipes **182** extending laterally across the tactile layer **130** and vertically to the surface of the tactile layer **130** at each key location. The system **100** can also include a light element **180** arranged on the top layer of the substrate and facing an input end of the network of light pipes. Thus, the system **100** can activate the light element **180** to illuminate the network of light pipes **182**, which funnels light to the surfaces of and illuminates the key locations.

However, the keyboard system **100** can include a set of light elements **180** arranged in any other configuration and configured to directly or indirectly illuminate key locations **132** or discrete key elements **140** in any other way.

As a person skilled in the art will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the embodiments of the invention without departing from the scope of this invention as defined in the following claims.

We claim:

1. A keyboard system comprising:

a substrate comprising:

a first layer comprising a first array of spiral traces, each spiral trace in the first array of spiral traces:

coiled in a first direction; and

defining a first end and a second end; and

a second layer arranged below the first layer and comprising a second array of spiral traces, each spiral trace in the second array of spiral traces:

coiled in a second direction opposite the first direction;

defining a third end and a fourth end, the third end electrically coupled to a second end of a first spiral trace in the first array of spiral traces; and

cooperating with an adjacent spiral trace to form a first loop of an inductor, in an array of inductors across the substrate;

a tactile layer:

arranged over the substrate; and

defining an array of key locations over the array of inductors;

an array of magnetic elements, each magnetic element in the array of magnetic elements:

arranged within the tactile layer at a key location in the array of key locations;

configured to inductively couple to an adjacent inductor in the array of inductors; and

configured to move relative to the adjacent inductor responsive to application of a force on the tactile layer at the key location; and

a controller configured to:

read electrical values from the array of inductors; and

at a first time, in response to detecting a first change in electrical value at a first inductor, in the array of inductors:

register a first keystroke of a first key type associated with a first key location, in the array of key locations, defined over the first inductor; and

drive an oscillating voltage across the first inductor during a first haptic feedback cycle to:

induce alternating magnetic coupling between the first inductor and a first magnetic element, in the array of magnetic elements, arranged within the tactile layer at the first key location; and

oscillate the tactile layer, at the first key location, relative to the substrate.

2. The keyboard system of claim **1**, wherein the controller is further configured to

read a second set of electrical values from the array of inductors at a second time succeeding the first time; and

in response to detecting a second change in electrical value at a second inductor, in the array of inductors, in the second set of electrical values:

register a second keystroke of a second key type different from the first key type and associated with a second key location, in the array of key locations, defined over the second inductor; and

drive the oscillating voltage across the second inductor during a second haptic feedback cycle to:

induce alternating magnetic coupling between the second inductor and a second magnetic element, in the array of magnetic elements, arranged within the tactile layer at the second key location; and

oscillate the tactile layer, at the second key location, relative to the substrate.

3. The keyboard system of claim **2**, wherein the controller is configured to:

read the second set of electrical values, from a subset of inductors in the array of inductors and excluding the first inductor, during the first haptic feedback cycle; and

initiate the second haptic feedback cycle at the second inductor prior to completion of the first haptic feedback cycle.

4. The keyboard system of claim **1**, wherein the controller is configured to:

read electrical values from the array of inductors by tracking voltage across the array of inductors;

detect the first change in electrical value comprising a first voltage of a first polarity across the first inductor at the first time;

register the first keystroke of the first key type in response to detecting the first voltage of the first polarity across the first inductor;

drive the oscillating voltage across the first inductor during the first haptic feedback cycle in response to registering the first keystroke;

detect a second voltage of a second polarity, opposite the first polarity, across the first inductor at a second time succeeding the first time;

register release of the first keystroke from the first key location on the tactile layer in response to detecting the second voltage at the second polarity across the first inductor; and

drive a second oscillating voltage across the first inductor during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location.

5. The keyboard system of claim 4, wherein the controller is configured to:

register the first keystroke of the first key type in response to the first voltage exceeding a first threshold voltage magnitude;

drive the oscillating voltage across the first inductor at a first frequency during the first haptic feedback cycle in response to registering the first keystroke;

register release of the first keystroke from the first key location on the tactile layer in response to the second voltage exceeding a second threshold voltage magnitude less than the first threshold voltage magnitude; and

drive the second oscillating voltage across the first inductor at a second frequency greater than the first frequency during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location.

6. The keyboard system of claim 1, wherein the controller is configured to:

read electrical values from the array of inductors by tracking current flow through the array of inductors;

detect the first change in electrical value comprising a first current moving through the first inductor in a first direction at the first time;

register the first keystroke of the first key type in response to detecting the first current moving through the first inductor in the first direction;

drive the oscillating voltage across the first inductor during the first haptic feedback cycle in response to registering the first keystroke;

detect a second current moving through the first inductor in a second direction opposite the first direction at a second time succeeding the first time;

register release of the first keystroke from the first key location on the tactile layer in response to detecting the second current moving through the first inductor in the second direction; and

drive a second oscillating voltage across the first inductor during a second haptic feedback cycle in response to registering release of the first keystroke from the first key location.

7. The keyboard system of claim 1:

wherein the tactile layer comprises an elastic sublayer:

interposed between the substrate and the array of magnetic elements;

configured to locally compress to enable movement of the first magnetic element toward the first inductor responsive to application of force over the first key location on the tactile layer; and

configured to locally compress to enable movement of a second magnetic element, in the array of magnetic elements, toward a second inductor, in the array of inductors, responsive to application of force over a second key location, in the array of key locations, on the tactile layer;

wherein the first magnetic element inductively couples to the first inductor and induces current flow in a first direction through the first inductor responsive to movement toward the first inductor;

wherein the second magnetic element inductively couples to the second inductor and induces current flow in the first direction through the second inductor responsive to movement toward the second inductor; and

wherein the controller is further configured to, at a second time, in response to detecting a second change in electrical value at the second inductor:

register a second keystroke of a second key type associated with the second key location defined over the second inductor; and

drive the oscillating voltage across the second inductor during a second haptic feedback cycle to:

induce alternating magnetic coupling between the second inductor and the second magnetic element arranged within the tactile layer at the second key location; and

oscillate the tactile layer, at the second key location, relative to the substrate.

8. The keyboard system of claim 1:

wherein the tactile layer comprises an elastic sublayer:

defining a unitary structure; and

forming a contiguous surface spanning the array of key locations; and

wherein each magnetic element in the array of magnetic elements comprises a magnet overmolded in the elastic sublayer below a key location in the array of key locations.

9. The keyboard system of claim 1:

wherein the tactile layer comprises an elastic sublayer arranged over the substrate and a set of discrete rigid key elements; and

wherein each discrete rigid key element, in the set of discrete rigid key elements:

is coupled to a discrete region of the elastic sublayer over an inductor in the array of inductors;

defines a key location in the array of key locations;

houses a magnetic element in the array of magnetic elements; and

is configured to compress the discrete region of the elastic sublayer and to move the magnetic element toward the inductor responsive to application of a force on the discrete rigid key element, the magnetic element inducing current flow through the inductor responsive to motion toward the inductor.

10. The keyboard system of claim 1:

wherein the substrate defines an array of bores adjacent the array of inductors;

wherein the tactile layer comprises a set of discrete key elements arranged over the substrate and cooperating to form the tactile layer; and

wherein each discrete key element, in the set of discrete key elements:

defines a key face;

comprises an elastic post extending rearward from the key face;

is installed over an inductor, in the array of inductors, with the elastic post:

extending through a bore, in the array of bores, in the substrate; and

retaining the discrete key element over the substrate;

houses a magnetic element in the array of magnetic elements; and

is configured to compress against the substrate and to move the magnetic element toward the inductor responsive to application of a force on the key face, the magnetic element inducing current flow through the inductor responsive to motion toward the inductor.

11. The keyboard system of claim **1**:

wherein the first magnetic element comprises:

a first magnet:

arranged over the first inductor on a first side of a primary axis of the first inductor; and

defining a first polarity facing the first inductor; and

a second magnet:

adjacent the first magnet;

arranged over the first inductor on a second side of a primary axis of the first inductor opposite the first magnet; and

defining the first polarity facing away from the first inductor; and

wherein the controller is configured to drive the oscillating voltage across the first inductor during the first haptic feedback cycle to:

induce alternating magnetic coupling between the first inductor, the first magnetic, and the second magnet; and

oscillate the tactile layer, at the first key location, parallel to the substrate.

12. The keyboard system of claim **1**:

wherein the first layer of the substrate further comprises a third array of spiral traces, each spiral trace in the third array of spiral traces:

adjacent a first spiral trace in the first array of spiral traces;

coiled in the second direction; and

defining a fifth end and a sixth end, the fifth end electrically coupled to the first end of the first spiral trace;

wherein the second layer of the substrate further comprises a fourth array of spiral traces, each spiral trace in the fourth array of spiral traces:

adjacent a second spiral trace in the second array of spiral traces;

coiled in the first direction;

defining a seventh end and an eighth end, the seventh end electrically coupled to a sixth end of a third spiral trace in the third array of spiral traces;

cooperating with a first spiral trace in the first array of spiral traces, the second spiral trace, and the third spiral trace to form an inductor, in the array of inductors, below a key location in the array of key locations; and

cooperating with the third spiral trace to form a second loop of the inductor, the second loop of the inductor defining a secondary axis parallel to and offset from a primary axis of a first loop of the inductor;

wherein the first magnetic element comprises:

a first magnet:

arranged over a primary axis of a first loop of the first inductor; and

defining a first polarity facing the first inductor; and

a second magnet:

adjacent the first magnet;

arranged over a secondary axis of a second loop of the first inductor; and

defining the first polarity facing away from the first inductor; and

wherein the controller is configured to drive the oscillating voltage across the first inductor during the first haptic feedback cycle to:

induce alternating magnetic coupling between the first magnet and the first loop of the first inductor;

induce alternating magnetic coupling between the second magnet and the second loop of the first inductor; and

oscillate the tactile layer, at the first key location, normal to the substrate.

13. The keyboard system of claim **1**:

wherein the tactile layer comprises an array of translucent regions arranged within the array of key locations;

wherein each inductor, in the array of inductors, defines a spiral trace:

fabricated on a first layer of the substrate facing the tactile layer; and

facing a key location in the array of key locations; and

further comprising an array of light elements, each light element in the array of light elements:

arranged on the first layer of the substrate adjacent a spiral trace of an inductor in the array of inductors;

facing a key location, in the array of key locations, of the tactile layer; and

configured to illuminate a translucent region within the key location.

14. A keyboard system comprising:

a substrate comprising:

an array of electrodes; and

an array of inductors, each inductor in the array of inductors paired with an electrode in the array of electrodes;

a tactile layer:

arranged over the substrate; and

defining an array of key locations over the array of inductors;

an array of magnetic elements, each magnetic element in the array of magnetic elements:

arranged within the tactile layer at a key location in the array of key locations; and

configured to inductively couple to an adjacent inductor in the array of inductors; and

a controller configured to:

couple drive electrodes in the array of electrodes to a reference voltage;

read sense voltages from sense electrodes in the array of electrodes;

at a first time, in response to a first sense voltage, read from a first sense electrode in the array of electrodes, exceeding a first threshold voltage corresponding to a minimum keystroke force:

register a first keystroke of a first key type associated with a first key location, in the array of key locations, defined over the first sense electrode; and

drive an oscillating voltage across a first inductor, arranged below, the first sense electrode, during a first haptic feedback cycle to:

induce alternating magnetic coupling between the first inductor and a first magnetic element, in the array of magnetic elements, arranged within the tactile layer at the first key location; and

oscillate the tactile layer, at the first key location, relative to the substrate.

15. The keyboard system of claim **14**, wherein the controller is configured to:

at second time succeeding the first time, read a second set of electrical values from the array of electrodes; and

register release of the first keystroke from the first key location in response to a second sense voltage, read from the first sense electrode at the second time, differing from the stored baseline voltage for the first sense electrode by less than a second threshold voltage, the second threshold voltage less than the first threshold voltage.

16. A keyboard system comprising:
a substrate comprising:
an array of electrodes; and
an array of inductors arranged below the array of electrodes;
a tactile layer:
arranged over the substrate; and
defining an array of key locations over the array of sense electrode and the array of inductors;
an array of magnetic elements, each magnetic element in the array of magnetic elements:
arranged within the tactile layer at a key location in the array of key locations; and
configured to inductively couple to an adjacent inductor in the array of inductors; and
a controller configured to:
read electrical values in the form of capacitance values from the array of electrodes; and
at a first time, in response to a first capacitance value, read from a first sense electrode in the array of electrodes, exceeding a first threshold capacitance value corresponding to a minimum keystroke force:
register a first keystroke of a first key type associated with a first key location, in the array of key locations, defined over the first sense electrode; and
drive an oscillating voltage across a first inductor, arranged below, the first sense electrode, during a first haptic feedback cycle to:
induce alternating magnetic coupling between the first inductor and a first magnetic element, in the array of magnetic elements, arranged within the tactile layer below the first key location; and
oscillate the tactile layer, at the first key location, relative to the substrate.

17. The keyboard system of claim **16**:
wherein the tactile layer comprises an elastic sublayer:
interposed between the substrate and the array of magnetic elements;
configured to locally compress to enable movement of the first magnetic element toward the first electrode responsive to application of force over the first key location on the tactile layer; and
configured to locally compress to enable movement of a second magnetic element, in the array of magnetic elements, toward a second electrode, in the array of electrode, responsive to application of force over a second key location, in the array of key locations, on the tactile layer;
wherein the first magnetic element affects capacitance of the first electrode responsive to movement of the first magnetic element toward the first inductor;
wherein the second magnetic element affects capacitance of the second electrode responsive to movement of the second magnetic element toward the second inductor; and
wherein the controller is further configured to, at a second time, in response to detecting a second change in electrical value at the second inductor:
register a second keystroke of a second key type associated with the second key location defined over the second inductor; and
drive the oscillating voltage across the second inductor during a second haptic feedback cycle to:
induce alternating magnetic coupling between the second inductor and the second magnetic element arranged within the tactile layer at the second key location; and
oscillate the tactile layer, at the second key location, relative to the substrate.

18. A keyboard system comprising:
a substrate comprising an array of inductors;
a tactile layer:
arranged over the substrate; and
defining an array of key locations over the array of inductors;
an array of magnetic elements, each magnetic element in the array of magnetic elements:
arranged within the tactile layer at a key location in the array of key locations;
configured to inductively couple to an adjacent inductor in the array of inductors; and
configured to move relative to the adjacent inductor responsive to application of a force on the tactile layer at the key location; and
a controller configured to:
at a first time, read a first set of electrical values corresponding to current flow through the array of inductors;
in response to detecting a first current in a first direction through a first inductor, in the array of inductors, based on the first set of electrical values:
register a first keystroke of a first key type associated with a first key location, in the array of key locations, defined over the first inductor; and
drive an oscillating voltage across the first inductor during a first haptic feedback cycle to:
induce alternating magnetic coupling between the first inductor and a first magnetic element, in the array of magnetic elements, arranged within the tactile layer at the first key location; and
oscillate the tactile layer, at the first key location, relative to the substrate;
at a second time succeeding the first time, read a second set of electrical values corresponding to current flow through the array of inductors; and
in response to detecting a second current in a second direction, opposite the first direction, through the first inductor based on the second set of electrical values:
register release of the first keystroke from the first key location on the tactile layer; and
drive a second oscillating voltage across the first inductor during a second haptic feedback cycle.

19. A keyboard system comprising:
a substrate comprising an array of inductors, each inductor in the array of inductors defining a spiral trace fabricated on a first layer of the substrate;
a tactile layer:
arranged over the substrate;
defining an array of key locations facing the array of inductors; and
comprising an array of translucent regions arranged within the array of key locations;
an array of light elements, each light element in the array of light elements:
arranged on the first layer of the substrate adjacent a spiral trace of an inductor in the array of inductors;

facing a key location, in the array of key locations, of the tactile layer; and

configured to illuminate a translucent region, in the array of translucent regions, within the key location;

an array of magnetic elements, each magnetic element in the array of magnetic elements:

arranged within the tactile layer at a key location in the array of key locations;

configured to inductively couple to an adjacent inductor in the array of inductors; and

configured to move relative to the adjacent inductor responsive to application of a force on the tactile layer at the key location; and

a controller configured to:

read electrical values from the array of inductors; and

at a first time, in response to detecting a first change in electrical value at a first inductor, in the array of inductors:

register a first keystroke of a first key type associated with a first key location, in the array of key locations, defined over the first inductor; and

drive an oscillating voltage across the first inductor during a first haptic feedback cycle to:

induce alternating magnetic coupling between the first inductor and a first magnetic element, in the array of magnetic elements, arranged within the tactile layer at the first key location; and

oscillate the tactile layer, at the first key location, relative to the substrate.

20. A keyboard system comprising:

a substrate:

comprising an array of inductors; and

defining an array of bores adjacent the array of inductors;

a tactile layer comprising a set of discrete key elements arranged over the substrate, each discrete key element in the set of discrete key elements:

defining a key face arranged over an inductor in the array of inductors;

comprising an elastic post:

extending rearward from the key face through a bore, in the array of bores, in the substrate; and

retaining the discrete key element over the substrate; and

configured to compress against the substrate responsive to application of a force on the key face;

an array of magnetic elements, each magnetic element in the array of magnetic elements:

arranged within the tactile layer at a discrete key element in the array of discrete key elements;

configured to inductively couple to an adjacent inductor in the array of inductors; and

configured to move relative to the adjacent inductor responsive to application of a force on the tactile layer at the discrete key element; and

a controller configured to:

read electrical values from the array of inductors; and

at a first time, in response to detecting a first change in electrical value at a first inductor, in the array of inductors:

register a first keystroke of a first key type associated with a first discrete key element, in the array of discrete key elements, defined over the first inductor; and

drive an oscillating voltage across the first inductor during a first haptic feedback cycle to:

induce alternating magnetic coupling between the first inductor and a first magnetic element, in the array of magnetic elements, arranged within the tactile layer at the first discrete key element; and

oscillate the tactile layer, at the first discrete key element, relative to the substrate.

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